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Characterization of Emissions from the Simulated Open Burning of Scrap Tires

Acurex Corp., Research Triangle Park, NC

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16. ABSTRACT The report gives results of a small-scale combustion study, designed to collect, identify, and quantify products emitted during the simulated open burning of scrap tires. Fixed combustion gas, volatile and semi-volatile organic, particulate, and airborne metals data were collected under two burn conditions that varied by the size of tire material. Burn rates, varied by material size, were used to estimate potential emissions of identified products. Total estimated emissions of semi-volatile organics ranged from 10 to 50 g/kg of tire material burned. Monoaromatic and polyaromatic hydrocarbons were the predominant emission products identified. The presence of benzo(a)pyrene (BAP) in particulate extracts is of particular concern because it is a known carcinogen. The presence of zinc in gaseous particulate collection was also verified and quantified. Several trends were evaluated relating emission products to burn rates.

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Combustion	Characterization	21B
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PREFACE

The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State and Local air pollution control agencies. Three levels of assistance can be accessed through the CTC. First, a CTC HOTLINE has been established to provide telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The technical guidance projects, such as this one, focus on topics of national or regional interest that are identified through contact with State and Local agencies. In this case, the CTC became interested in examining pollutants emitted from open air tire burning, and providing qualitative and semi-quantitative estimates of the emissions. The document discusses a series of small-scale controlled simulations of open air tire burning that were performed at the Environmental Research Center in Research Triangle Park, NC.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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SECTION 1

INTRODUCTION

Approximately 240 million vehicle tires are discarded annually.[1] Although viable methods for reclamation exist, less than 25 percent are re-used or re-processed. The remaining 170 million scrap tires are discarded in landfills, above-ground stockpiles, or illegal dumps.

Many landfills are refusing to accept tires because they present not only disposal but also health-related problems. After burial, tires often float to the surface and become partially filled with water. Cutting the tire in half or in pieces can reduce this tendency. However, it is very costly to cut or shred tires into a condition suitable for landfill, and in any event, many sites lack the necessary equipment. Steel-belted radials which comprise the majority of the nation's discarded tires, are particularly difficult to cut and/or shred. Often, they are simply stockpiled or illegally dumped. These stockpiles and dumps can become a breeding ground for many insects, especially mosquitos, where water collects in the tires and creates an ideal breeding habitat. The introduction and spread of several mosquito species has been directly attributed to the presence of refuse tires.[2]

The growing incidence of tire fires creates another potential health hazard. More tire stockpiles and illegal dumps are coming into existence, and with them the occurrence of tire fires. These fires, often started by arson, generate a huge amount of heat, making them extremely difficult to extinguish. Some of these tire fires have continued for months. For example, the Rhinehart tire fire in Winchester, Virginia, burned for nearly 9 months,[3] potentially exuding large quantities of harmful compounds.

Very little information is available in regard to the open burning of scrap tires. Information is available as to the composition of tires. Table 1-1 lists the proximate and ultimate analyses of a typical tire.

TABLE 1-1. ANALYSIS OF A PASSENGER CAR TIRE[4]

Proximate, percent:	
Moisture	0.5
Volatile Matter	62.3
Fixed Carbon	31.5
Ash	5.7
Ultimate, Percent	
Hydrogen	7.1
Carbon	83.2
Nitrogen	0.3
Oxygen	2.5
Sulfur	1.2
Ash	5.7

The EPA's Control Technology Center (CTC) received numerous requests from state and local agencies nationwide for information pertaining to tire fires and their effects. Because very little information was available, the steering committee felt a study investigating this potential problem was warranted. Through the guidance of the Combustion Research Branch (CRB) of EPA's Air and Energy Engineering Research Laboratory (AEERL), Acurex conducted a study which identified and quantified organic and inorganic emission products produced during the simulated open combustion of scrap tires.

SECTION 2

EXPERIMENTAL APPROACH

2.1 PROJECT DESCRIPTION

The project consisted of a parametric study to collect organic and inorganic emissions from the simulated open combustion of scrap tires. Small quantities (10-20 lb, 4.5-9.0 kg) of scrap-tire material were burned under two different controlled conditions determined by the size of the material (see Section 2.3.1). The conditions were evaluated in duplicate on successive days. An existing burn hut used for similar projects was modified to accommodate this task. A separate outbuilding housed the required organic and particulate sampling equipment. CRB's Hazardous Air Pollutants Mobile Laboratory (HAPML) was used to monitor fixed combustion gases. Organics were collected using the Volatile Organic Sampling Train (VOST) and a semi-volatile collection system using XAD-2 and particulate filters. Particulate was also collected to assess airborne metals. The organic constituents were analyzed both qualitatively and quantitatively by GC/MS, GC/FID, HPLC, and gravimetric methodologies.

2.2 EXPERIMENTAL APPARATUS

2.2.1 Burn Hut

The burn hut was an 8-ft x 8-ft x 8-ft (2.4-m x 2.4-m x 2.4-m) outbuilding modified for small-scale combustion experiments (see Figure 2-1). The building had been fitted with a cooled, dilution air handling system capable of delivering nominally 1,200 ft^3/min (34.0 m^3/min). A 16-in x 16-in x 16-in (.4-m x .4-m x .4-m) stainless-steel burn pit insulated with fire brick was mounted on a weigh scale to continuously monitor weight differential. A PM_{10} ambient sampler was located in the hut to collect particulate matter 10 µm in diameter or less. A deflector shield was located 4 ft (1.2 m) over the pit to deflect flames, protect the ceiling, and enhance ambient mixing. The gaseous sample duct opening was located directly over the deflector shield. This duct transported a representative portion of gaseous

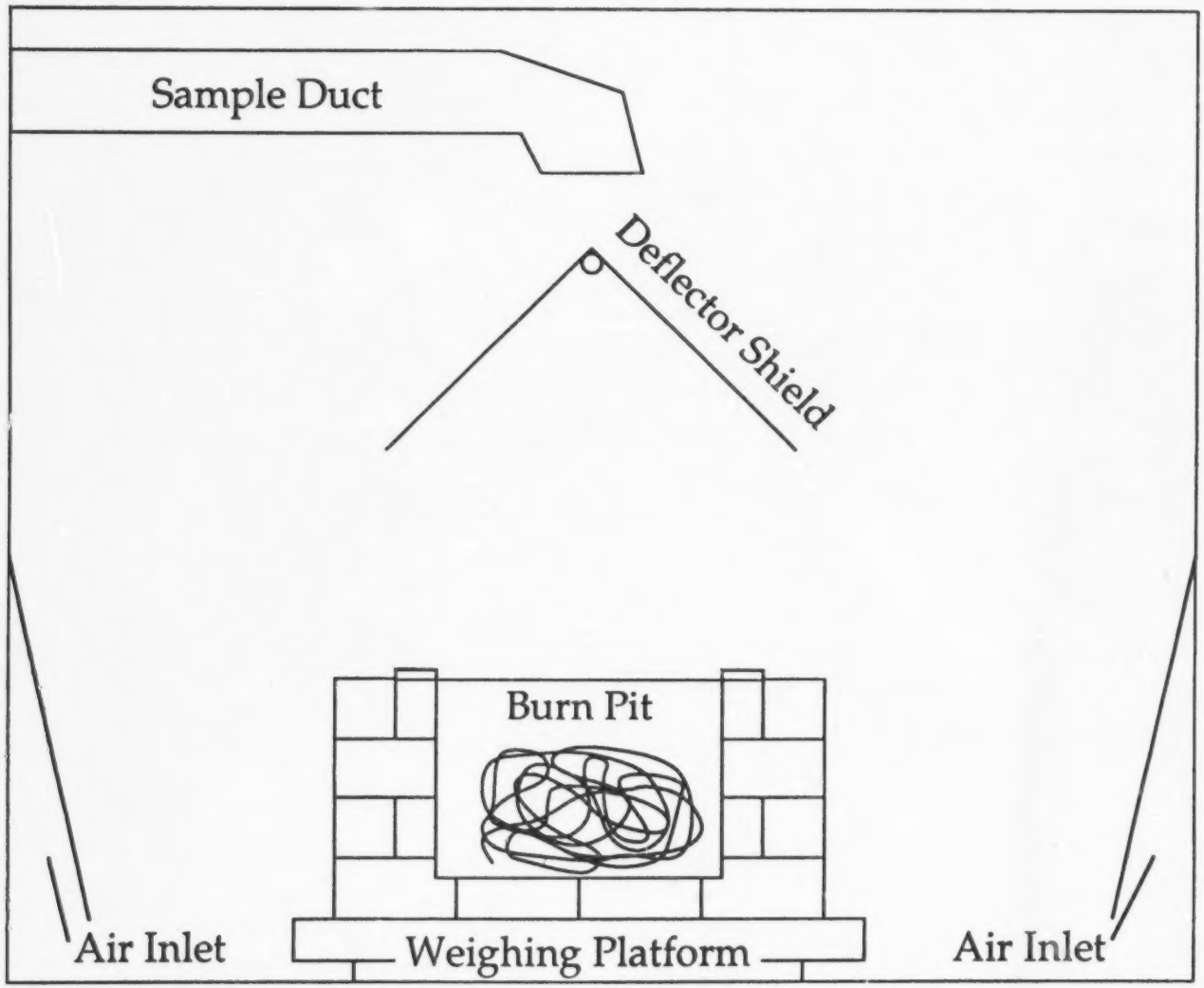

Figure 2-1. Diagram of burn hut.

sample to the sample shed immediately adjacent to the burn hut (see Figure 2-2). The duct was insulated outside the hut to minimize heat loss and condensation of organics.

2.2.2 Sample Shed

The sample shed contained the majority of the sampling equipment: the VOST system, the semi-volatile organic collection system, the airborne metals particulate collection system, the continuous emission monitor (CEM), the particulate removal system, and the digital readout for the weigh scale. All gaseous samples were extracted from a sampling manifold within the duct. The manifold consisted of 3/8-in O.D. (9.5 mm) stainless-steel tube probes positioned so that the opening was directed into the flow of the sample stream. The sample stream was pulled into the sample shed by vacuum, using an induced draft (ID) fan located downstream of the sample manifold. Figure 2-3 diagrams the individual sampling systems and illustrates how each obtained a representative sample from the duct.

Volatile organics were collected on Tenax-GC using the VOST system, which is fully described in Method 0030 found in SW-846.[4] Semi-volatile organics were collected using a sample system modified for use in this study. A 3/8-in O.D. (9.5 mm) stainless-steel tube was connected to a filter housing. Particulate was collected on a 142 mm, teflon-coated, glass-fiber filter located in the filter housing. Downstream of the filter, a water-cooled condenser normally used for glass-SASS applications was located upstream of the XAD-2 canister. This canister contained roughly 150 g of the organic sorbent material. The XAD-2 module was connected to the pump and metering system, which was run under vacuum. A similar system without the condenser and XAD-2 module was used for the airborne metals particulate capture. In this case, a quartz-fiber filter was used. Particulate removal of the CEM gaseous sample was accomplished by a high-surface area/low-pressure drop spun-glass filter housed in a heated box that was directly affixed to the sample manifold.

2.2.3 HAPML

A heated sample line was connected from the particulate conditioning filter to the sample manifold in the HAPML. A portion of the heated sample was routed to the SO_2 analyzer as well as to the Total Hydrocarbon (THC) analyzer. The remaining portion of the sample stream was further conditioned for moisture removal by a refrigeration condenser and silica gel before being routed to the O_2, CO_2, and

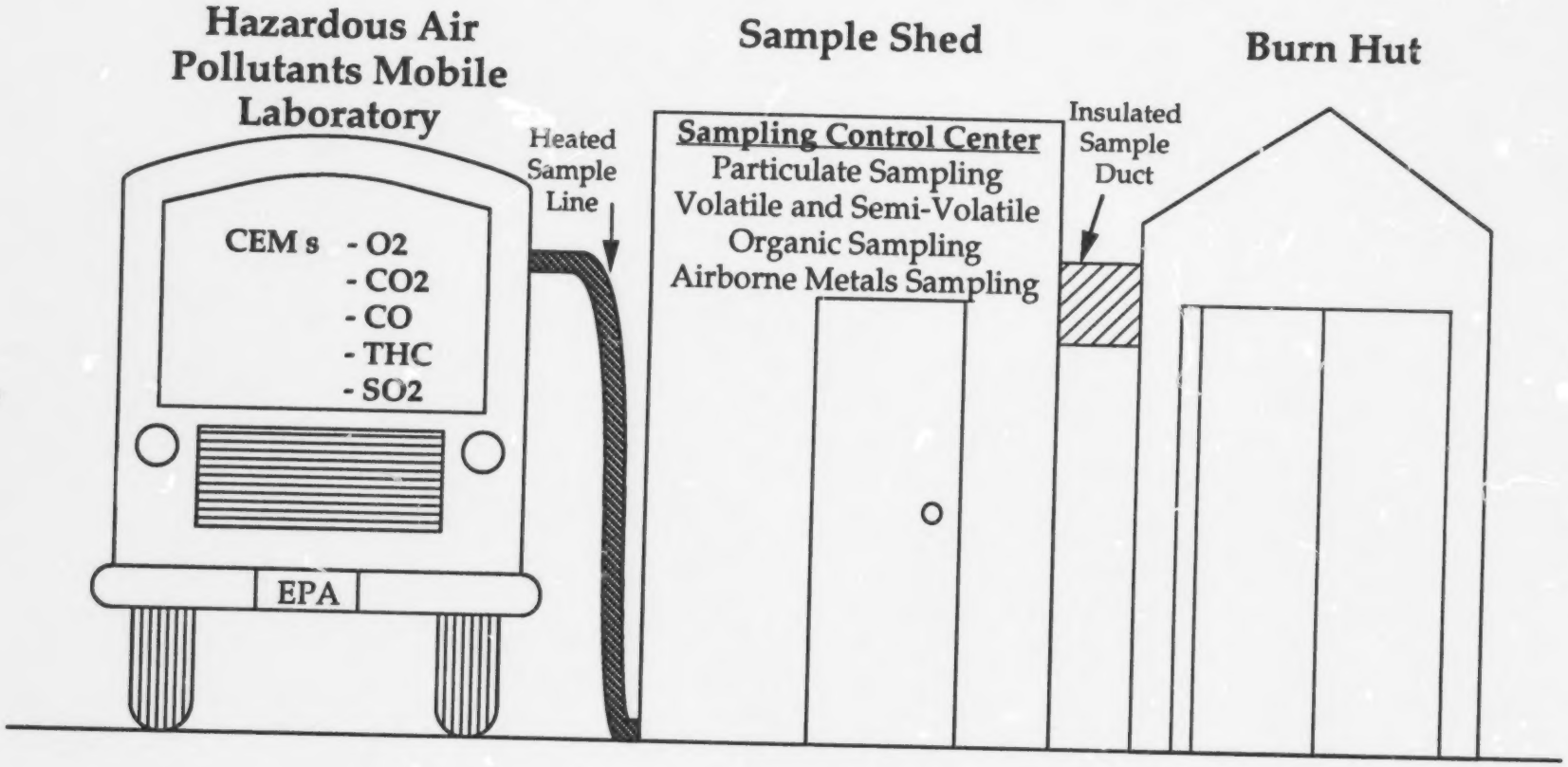

Figure 2-2. Locations of required test equipment.

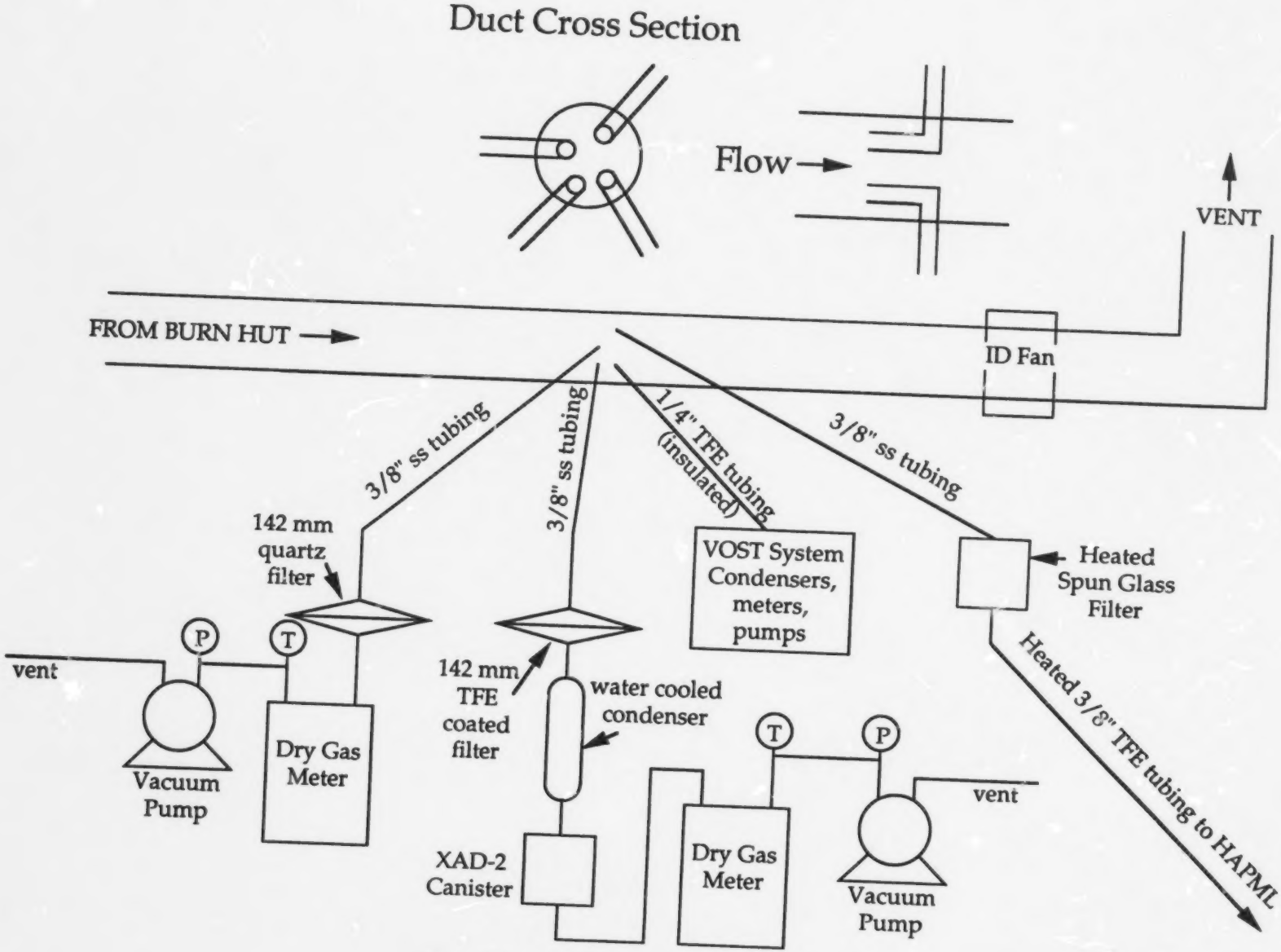

Figure 2-3. Diagram of sampling systems used.

CO analyzers. The analog output of the individual analyzers was recorded by a computerized data acquisition system using 5 min averages. Data were stored continuously.

2.3 EXPERIMENTAL METHODS AND PROCEDURES

2.3.1 Simulation of Open Air Combustion

Representative tire material was obtained from local tire dealers. Owing to the difficulty in cutting steel-belted radials, bias ply tires were used in this study. Both truck and passenger car tires were sampled. The tires were cut into two distinct sizes to vary initial surface area and combustion rate. One size was ~1/4-1/6 of an entire tire and will be referred to as the "CHUNK" condition. The other size consisted of 2-in by 2-in pieces of tire and will be referred to as the "SHRED" condition.

Sufficient material was placed into the burn pit such that total weight approximated two tires (~30 lb, 13.6 kg), as indicated on the scale. Prior to tire material ignition, the CEMs were run for 15 min to obtain a background reading. During this time, the dilution air system was operating and continued to operate throughout the duration of test period. The dilution air system continuously added 1,200 ft^3/min (34.0 m^3/min) to the burn hut. After the baseline period had been established, the tire material was ignited with a propane torch. When combustion became self-sustaining (~5 min), the torch was removed and the hut door was closed.

With the exception of the first day of testing, 30 min elapsed prior to the initiation of the sampling equipment. On Day 1, sampling systems were activated after 15 min. At the start and end of each sample condition as well as roughly every 20 min, the time and tire material weight were recorded. Temperatures inside the burn hut and in the sample duct were also recorded at this time.

2.3.2 CEMs

Fixed combustion gases were measured continuously using on-line analyzers. Prior to sampling, a 3-point calibration was performed on each instrument. Once suitable linearity was verified, a span check before and after each sample period was conducted. This span check was used to verify instrument performance and integrity and to validate collected data.

The analog output of each analyzer was converted digitally and then acquired on a computer using 5 min averages. The data were continuously stored, and hardcopy was also produced.

2.3.3 Volatile Organics

Volatile organics were collected using an unmodified VOST system operated according to Method 0030 found in SW-846.[5] During this study, no stack probe was used. An insulated section of 1/4-in Teflon tubing affixed to the sampling manifold, was used to transport the gaseous sample from the sample duct to the VOST system. The sample was drawn through the Tenax and Tenax/charcoal tubes at a nominal flow rate of 0.5 L/min for 40 min, for a total sample of 20 L. The sample tube sets were submitted to quality control contamination checks (QC'd) prior to use and were stored refrigerated at 1 °C in Teflon bags both prior to and after use. Daily field blanks were performed, and all samples were analyzed within 30 days.

The VOST samples were analyzed by GC/MS on a purge and trap system devoted to VOST sample analyses. Method 5040 of SW-846 best represents the procedure used for sample analyses.[6] The identification of unknowns was accomplished using mass spectral library searches as well as investigator interpretation. Quantification of the identified unknowns was based upon the toluene response factor obtained during initial calibration.

Prior to calibration or the analysis of samples, the MS was tuned with perflourotributylamine (PFTBA) to linearize the working range of mass units (45-420 amu). Following initial linearization, a multipoint calibration using toluene was performed. This calibration was used to quantify the QC samples analyzed at the beginning and end of each sample period as well as after every third sample. The QC sample contained known concentrations of toluene and bromoflourobenzene (BFB). The BFB was used to confirm ion abundance criteria, thereby verifying mass linearity of the instrument.

As stated earlier, the tenax tube samples were analyzed on a dedicated purge and trap GC/MS system. The samples were desorbed in a clamshell heater maintained at 190 °C using a helium carrier at a nominal flow rate of 25 mL/min onto a Tenax trap at room temperature for 10 min. At this point, the trap was heated rapidly to 225 °C, and the carrier was directed onto a 30 m DB-624 megabore column. The carrier flow at this condition was nominally 5.6 mL/min. The oven temperature was maintained at 30 °C for 5 min; then a temperature ramp was invoked at 5 °C/min until reaching 160 °C, where the temperature was held for 15 more minutes. As the sample constituents eluted from the column, they passed through

a jet separator before being introduced into the MS. A spectral sweep from 45-420 amu was performed each second. Data were acquired and stored by computer. Integration of peak areas was performed by manually establishing baseline and integration limits. Identification of unknowns was accomplished using the system mass spectral library, employing both the forward and reverse searching capabilities. Compound boiling point was also used to help identify the unknown.

2.3.4 Semi-Volatile Organics

Semi-volatile organics were collected on both the particulate filters as well as the XAD-2 organic sorbent. The system used for this was a major modification of that used for glass SASS. The teflon-coated fiber filter used for particulate collection was desiccated, tared, and placed in aluminum foil and a zip-lock bag prior to use. After sample collection, the samples were stored refrigerated at 1 °C until being desiccated, weighed, and extracted. The filter housing system was located immediately upstream of the XAD-2 canister. Cleaned and QC'd XAD-2 resin was placed in the canisters, sealed in teflon bags, and stored refrigerated prior to use. After sampling, the canisters were resealed in the teflon bags and stored refrigerated until being extracted less than 14 days later. The gaseous sample was collected at an average flow rate of 2-2.5 cfm for ~3 h. During the "CHUNK" condition, the particulate filters became loaded to the point that replacements were required.

Organics were retrieved from the collection media by soxhlet extraction using dichloromethane. The XAD-2 was extracted separately from the particulate fraction. Following the 24-h extraction, the samples were concentrated to 10 mL using a 3-ball Snyder column system. All organic concentrates were stored refrigerated until needed.

Both the particulate extracts and the XAD-2 extracts were analyzed for total chromatographable organics (TCO)—(organic compounds with boiling points between 100-300 °C) and GRAV—(organic compounds with boiling points greater than 300 °C). The TCO analysis was done by GC/FID.[7] A multipoint calibration was conducted using an alkane mix standard. The C7, C10, C12, C14, C17 mix was used to quantify and identify the temperature window. All peaks with retention times falling between but not including the C7 and C17 retention times were quantified. The response factor of the sum of C10, C12, and C14 areas was used for quantification. The analysis was performed using a 30 m DB-5

megabore column with a flow rate of 8 mL/min. The 2-5 µL injection was made with the oven temperature held at 40 °C for 3 min and then ramped to 250 °C at 20 °C/min and held for 15 min after reaching final temperature.

The GRAV analysis was done gravimetrically. Aluminum weigh boats were desiccated, tared, and then filled with 0.5 mL of the organic extract and allowed to evaporate. After evaporation, the boats were again desiccated and weighed. Organic compounds with boiling points greater than 300 °C represent the net gain. The analysis was performed in duplicate and included an audit sample.

Identification of unknown organics was again accomplished using a GC/MS system. For liquid work, a Hewlett Packard GC/MSD system configured for capillary columns was used. Split injections of 1-2 µL at a ratio of 100:1 were introduced onto a 30 m SPB-5 capillary column. An initial oven temperature of 40 °C was maintained for 5 min before ramping the temperature to 250 °C at 5 °C/min. The final temperature was held for 15 min. Compounds were identified using library spectral matching. The Wiley Library was used during spectral searching and matching. Again, boiling points were used in assisting investigator interpretation in determining compound identity. In several cases, known standards were used to confirm identifications.

Quantification of unknowns was accomplished through comparison of the GC/MSD runs with injections run under similar conditions using a GC/FID system. The SPB-5 column is virtually identical to the DB-5 column used, the only real differences being in the manufacturer, stationary phase thickness, and column ID. The injections were made on the same system as was used for the TCO analyses. The only change made was to alter the temperature ramp to match that of the GC/MSD runs. Several standard mixes containing compounds identified by GC/MS were prepared and run on the GC/FID system. The retention times of these standards were used as markers to relate the MS runs with the FID runs. The elution order of the MS runs was assumed to be identical to that of the FID runs. A linear relationship between the retention times of the runs was determined, and, along with comparison of peak magnitude, compound identifications were assigned to the FID runs. Quantification of individual peaks was performed with the same response factor used for TCO quantifications.

A portion of the liquid concentrates was also analyzed for polycyclic aromatic hydrocarbons (PAHs). This analysis was subcontracted and used EPA Method 610 as the referenced procedure.[8]

Unfortunately, the reported concentrations were reported as µg/total sample. A problem arises in that the volume of sample sent for analysis was not originally known since it is normally not required. It is common practice however, to mark the level of liquid in each sample vial. After retrieving the sample vials, these marks were used to determine the initial volume of each sample sent. From this, total sample concentrations were determined.

2.3.5 Airborne Metals Particulate

Particulate matter was collected using a separate sampling system in order to characterize airborne metals emissions. A gaseous sample was drawn across a 142 mm quartz-fiber filter under vacuum at an average flow rate of 2-2.5 cfm for ~3 h. During the "CHUNK" condition, two particulate filters were required. The quartz filters used were desiccated and tared, then placed in aluminum foil and a zip-lock bag prior to use. Following sample collection, the samples were refrigerated until they were again desiccated and reweighed. Ultimately, the samples were delivered to an outside analytical laboratory for metals quantification. Specific metals common in tire-ash residue were chosen for quantification.[9] The samples were analyzed using inductively coupled argon plasma (ICAP) methodology.[10]

2.3.6 PM_{10} Particulate Collection

An Andersen medium volume ambient particulate sampler was used to collect particulate of 10 µm in diameter or less. The sampler is designed so that when a flow of 4 cfm is maintained on the system, particulate of 10 µm in diameter or less only is collected on the filter. The 110 mm fiber filters were desiccated and tared, then placed in aluminum foil and a zip-lock bag prior to use. Following sampling, the filters were desiccated and weighed to determine total amount collected.

SECTION 3

DATA, RESULTS, AND DISCUSSION

3.1 BURN RATE RESULTS

As stated earlier, the size of tire material was varied to alter the combustion conditions and to gain insight into the mechanisms governing burn rate. Table 3-1 contains summary data of the observed burn rates for the two conditions. Rates were calculated by dividing the amount of tire material burned by the length of the burn and then normalizing to a mass per hour basis. The data show that the "CHUNK" condition produced a higher burn rate than the "SHRED" condition. Almost double the amount of material was combusted during similar periods.

Although several trial burns were conducted prior to actual testing, the first day of testing under "CHUNK" condition resulted in modifying the amount of tire material ignited in the burn pit. Approximately 33 lb (15.0 kg) were used initially. The result was vigorous combustion; the potential for the fire to become uncontrollable was a concern. Temperatures in the burn hut and in the sample duct became dangerously high; therefore, investigators decided to reduce the weight of tire material for the three remaining tests to ~27 lb (12.3 kg). By doing so, no other major problems were observed relating to the actual burning of tire material.

Figures 3-1 through 3-4 are plots of the burn rate vs. the elapsed time of the test run. All plots show a high initial burn rate, but as time elapsed, it diminished. In both of the "SHRED" runs, after more than midway through the test period, the burn pit had to be agitated to sustain combustion. This agitation would account for the visible increase in burn rates occurring at that point.

Under both conditions, an initial high burn rate was observed to gradually level off until a steady rate was achieved. Examination of the tire material suggested a possible explanation. Along the tread portion, of the tires, a much thicker layer of rubber was found in relation to the sidewall. In addition, the rubber of the sidewall portion seemed impregnated into the belt material, yet the rubber in the tread

TABLE 3-1. BURN RATE SUMMARY DATA

DAY 1 CHUNK CONDITION TOTAL WEIGHT BURNED = 20.0 lb AVG BURN RATE = 6.2 lb/h		DAY 2 CHUNK CONDITION TOTAL WEIGHT BURNED = 16.4 lb AVG BURN RATE = 5.0 lb/h		DAY 1 SHRED CONDITION TOTAL WEIGHT BURNED = 10.6 lb AVG BURN RATE = 3.0 lb/h		DAY 2 SHRED CONDITION TOTAL WEIGHT BURNED = 11.8 lb AVG BURN RATE = 3.5 lb/h	
ELAPSED TIME (min)	BURN RATE (lb/h)	ELAPSED TIME (min)	BURN RATE (lb/h)	ELAPSED TIME (min)	BURN RATE (lb/h)	ELAPSED TIME (min)	BURN RATE (lb/h)
0	0	0	0	0	0	0	0
14	3.4	11	2.2	10	9.6	20	9.0
23	25.3	20	16.0	30	6.0	30	3.6
35	19.0	31	18.0	52	3.3	60	3.2
50	7.2	51	8.4	73	2.3	96	2.0
65	6.4	74	6.8	98	2.4	107	4.4
74	6.7	87	4.6	117	2.5	120	6.5
88	6.0	102	6.4	138	3.4	137	4.2
128	4.2	122	1.8	152	2.6	147	3.1
162	3.2	142	1.8	176	1.5	187	2.1
194	2.3	152	2.4	193	2.1	203	1.5
		196	1.1	214	2.3		

Note: 1 lb/h = 0.45 kg/h

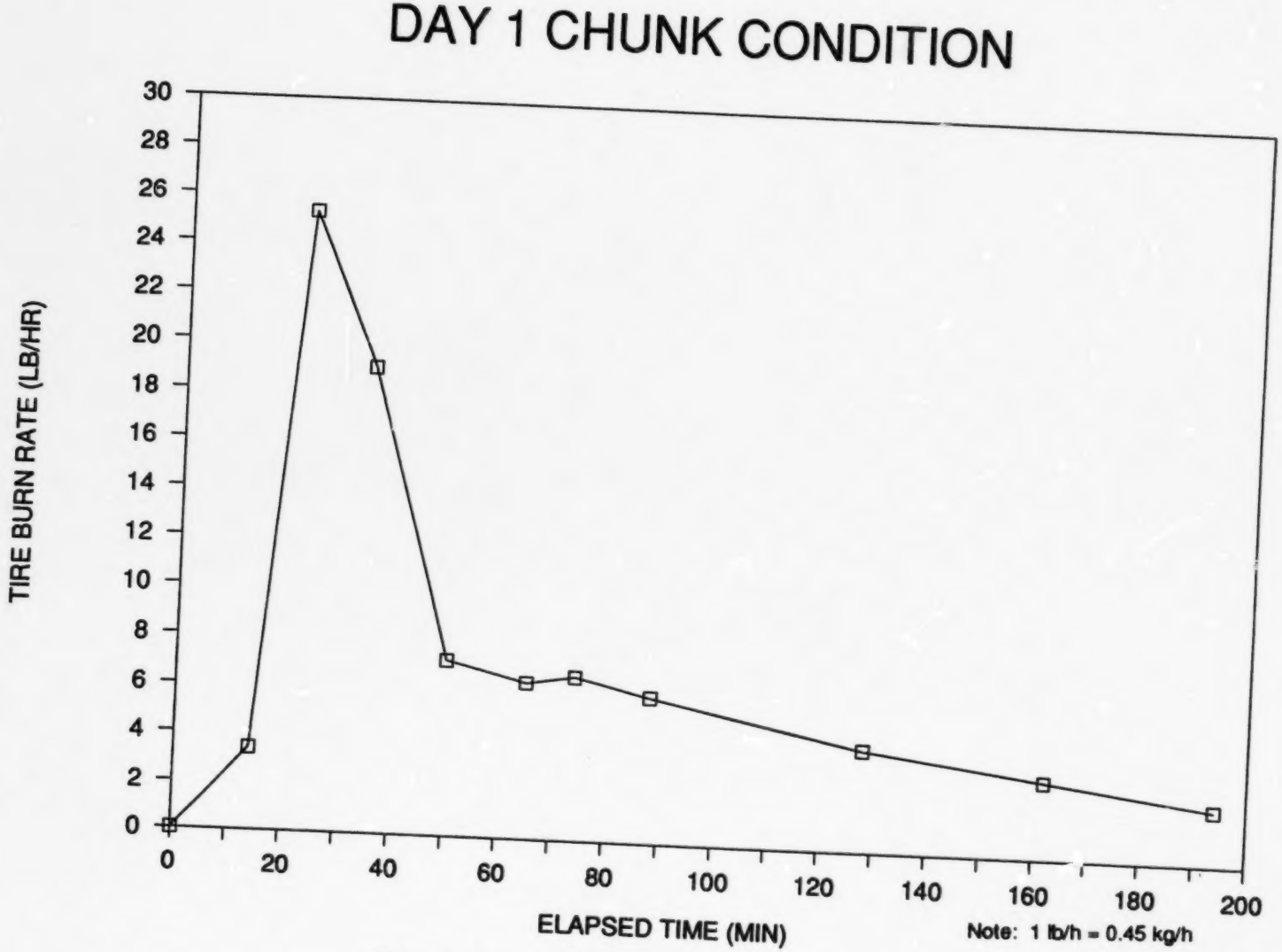

Figure 3-1. Burn rate vs. elapsed time—Day 1 "CHUNK" condition.

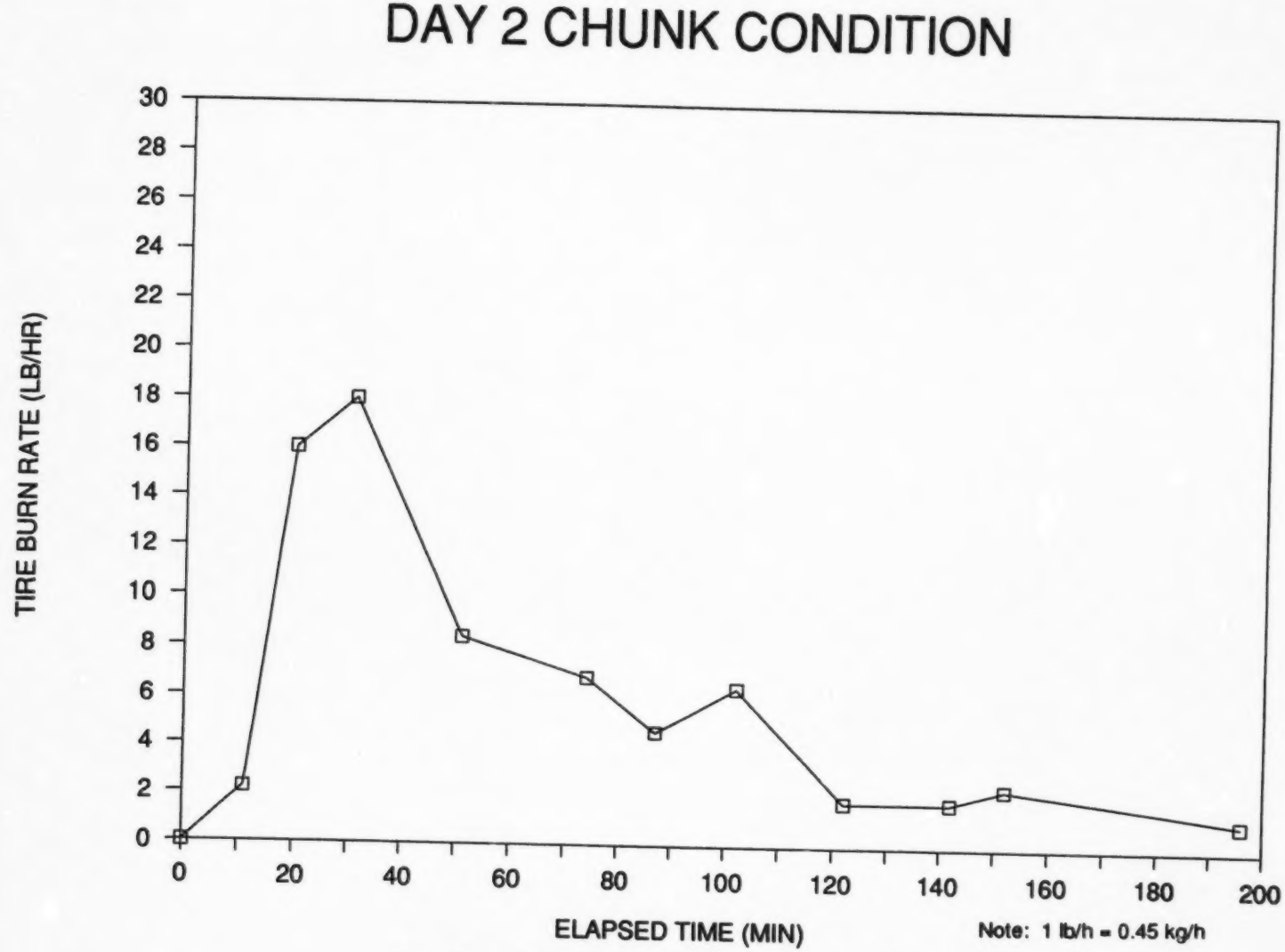

Figure 3-2. Burn rate vs. elapsed time—Day 2 "CHUNK" condition.

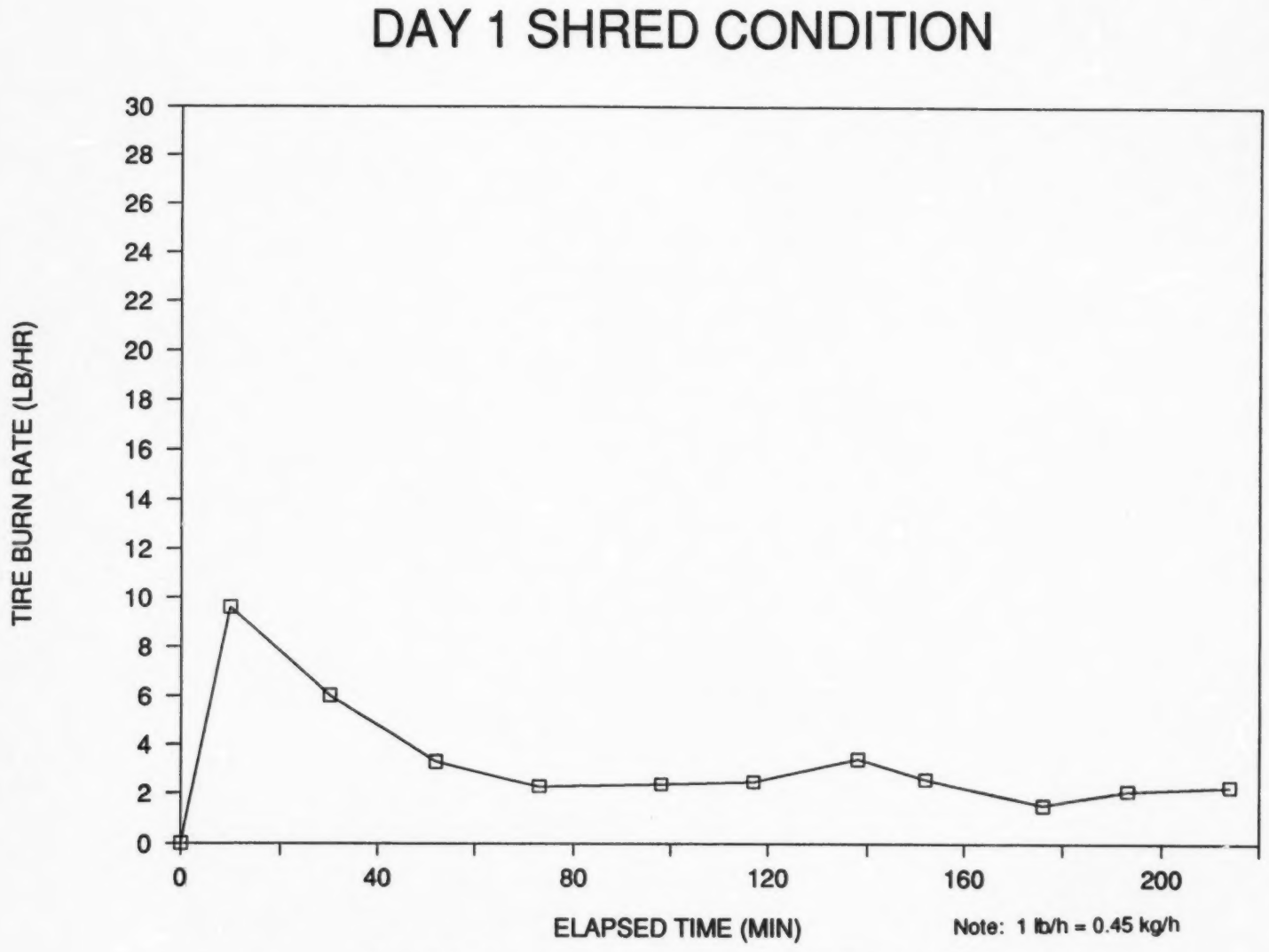

Figure 3-3. Burn rate vs. elapsed time—Day 1 "SHRED" condition.

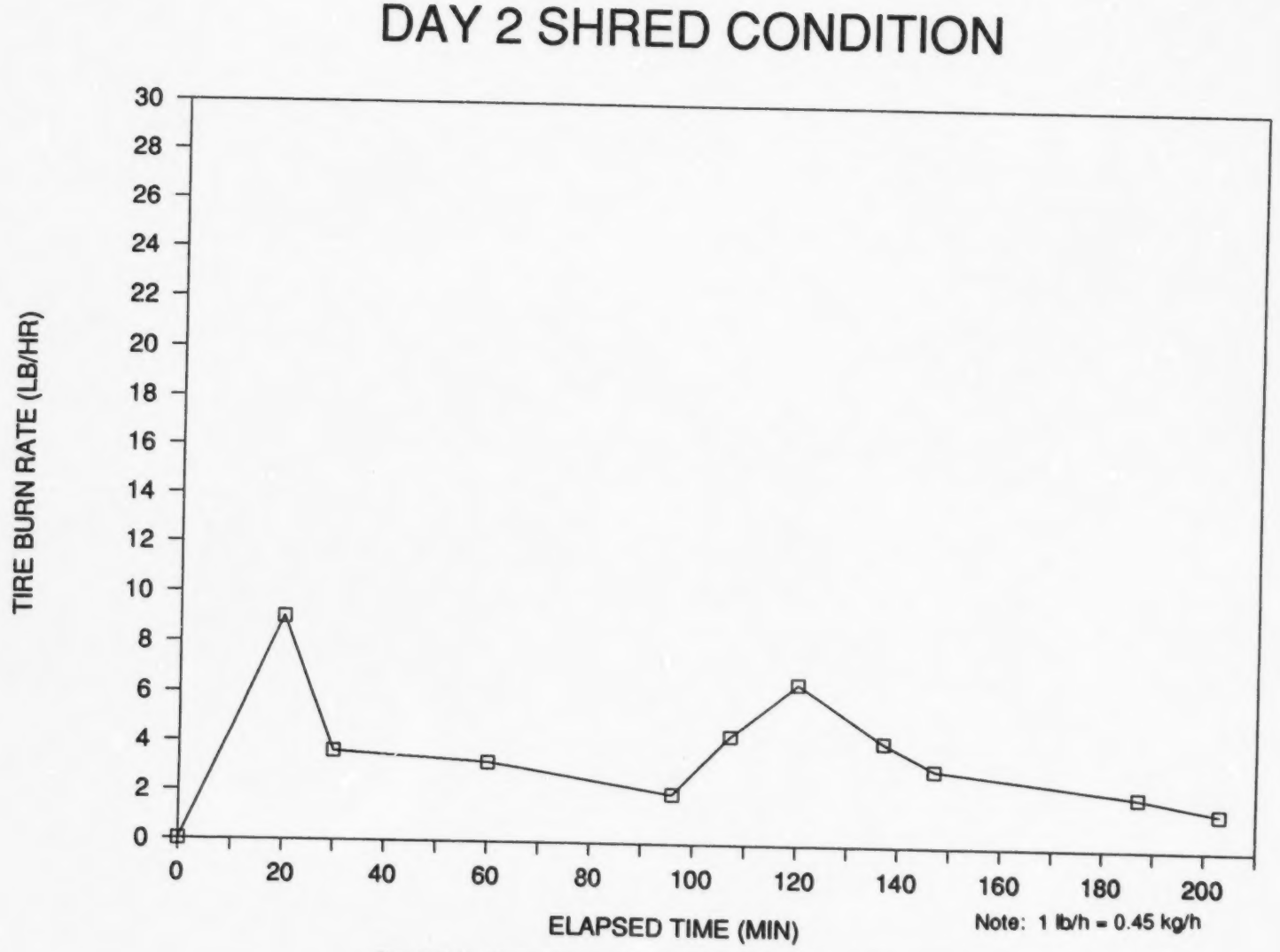

Figure 3-4. Burn rate vs. elapsed time—Day 2 "SHRED" condition.

surface contained no belt material. It may be that the tread material is consumed first while the belt containing rubber may be more difficult to burn and more uniform in its combustion.

3.2 CEM DATA

Combustion gas products were monitored continuously throughout the test period. Tables 3-2 through 3-5 contain the 5 min averages from the O_2, CO_2, SO_2, CO, and THC analyzers. On Day 1 of the "CHUNK" condition, the CO_2 analyzer was inoperable; therefore no data were acquired for this test point. It should also be noted that considerable problems were encountered with the SO_2 analyzer and that not all SO_2 data can be considered reliable. On Day 2 of the "CHUNK" condition, the instrument suddenly went negative midway through the run. The analyzer was rezeroed and the span was checked. The process was completed within 5 min and accounts for the absence of data at the 75 min mark. This problem was also encountered on Day 2 of the "SHRED" condition, with a 10 min lapse in data occurring at the 55 min mark. Instrument problems were encountered during the post-run span checks on both days of the "SHRED" condition. Although the predetermined accuracy limits of ±15 percent were exceeded, the SO_2 values are within the same order of magnitude and still provide insight into the combustion condition. They are therefore included.

Figures 3-5 through 3-8 are plots of CEM values over the elapsed time of the test. Comparing these plots with the respective plots pertaining to burn rate shows a relationship between high emissions of CO, SO_2, and THC at high burn rates.

3.3 VOLATILE ORGANIC EMISSION DATA

Identification of unknown organics using the MS proved to be highly successful. Table 3-6 lists the more than 50 compounds identified from the VOST samples collected during testing. The majority are aliphatically, olefinically, or acetylenically substituted aromatics. The predominant formation of aromatic hydrocarbons is likely due to the high thermodynamic stability of aromatic structures. A representative of each compound class is found in mono- through poly-substituted aromatic hydrocarbons. Cyclic alkanes, alkenes, and dienes were also present. It is not surprising to identify butadiene in the samples because it is a major constituent of the tire fabrication process. A halogenated

TABLE 3-2. TIRE BURN DATA: CHUNK CONDITION DAY 1[1]
Start Time: 13:03:23.14; Run Date: 1-31-1989

Time (min)	O_2 (% [dry])	CO (ppm [dry])	SO_2 (ppm [wet])	*THC (ppm [wet])
0	21.4	0	0	1
5	21.2	0	2	1
10	21.2	0	1	1
15	21.2	0	0	1
20	21.1	0	1	4
25	21.0	6	5	5
30	20.5	160	40	35
35	19.3	425	103	68
40	19.5	310	92	45
45	20.0	226	69	38
50	20.4	151	53	29
55	20.5	130	49	26
60	20.6	123	42	24
65	20.7	117	38	19
70	20.8	97	33	15
75	20.9	84	28	12
80	21.0	78	28	11
85	21.0	73	25	10
90	21.0	69	23	9
95	21.0	64	23	9
100	21.1	62	22	8
105	21.1	53	20	7
110	21.1	51	20	7
115	21.1	49	20	7
120	21.1	48	20	7
125	21.1	46	21	7
130	21.1	49	23	8
135	21.1	67	23	9
140	21.1	67	23	10
145	21.1	69	26	11
150	21.1	75	27	12
155	21.1	77	27	13
160	21.1	75	29	13
165	21.1	72	28	13
170	21.1	75	30	14
175	21.1	76	29	14
180	21.1	76	28	14
185	21.2	74	28	13
190	21.3	73	27	13
195	21.2	73	26	12
200	21.3	73	27	13
205	21.3	70	24	14

*As propane
1 No CO_2 data collected on this test point—instrument inoperable.

TABLE 3-3. TIRE BURN DATA: CHUNK CONDITION DAY 2
Start Time:14:20:57.53; Run Date: 2-01-1989

Time (min)	O_2 (% [dry])	CO_2 (% [dry])	CO (ppm [dry])	SO_2 (ppm [wet])	*THC (ppm [wet])
0	21.4	0	1	11	4
5	21.5	0	1	6	4
10	21.5	0	1	0	4
15	21.5	0	1	-3	4
20	21.5	0	2	-5	7
25	21.4	0	13	-1	8
30	20.9	0.1	140	39	32
35	20.5	0.3	142	47	22
40	20.4	0.5	196	67	40
45	20.5	0.6	195	68	41
50	20.7	0.5	160	61	36
55	20.8	0.4	150	60	35
60	20.9	0.4	138	55	31
65	21.1	0.3	109	45	24
70	21.1	0.3	110	41	23
75	21.1	0.3	121	38	23
80	21.2	0.2	100	-40	18
85	21.4	0.2	79	-49	11
90	21.4	0.2	59	28	6
95	21.6	0.1	46	24	9
100	21.6	0.1	39	26	8
105	21.6	0.1	40	22	7
110	21.6	0.1	58	23	9
115	21.6	0.1	75	28	13
120	21.6	0.1	84	29	14
125	21.7	0.1	82	24	15
130	21.7	0.1	76	18	13
135	21.7	0.1	75	20	13
140	21.8	0.1	76	18	11
145	21.8	0.1	63	12	11
150	21.9	0.1	64	14	10
155	21.9	0.1	75	19	19
160	22.0	0.1	74	21	19
165	21.9	0.1	79	22	22
170	22.0	0.1	69	23	22
175	22.0	0.1	67	21	20
180	22.0	0.1	68	21	17
185	22.0	0.1	69	20	17
190	22.0	0.1	69	21	17
195	22.0	0.1	69	23	19
200	22.0	0.1	67	25	17
205	22.0	0.1	59	22	18
210	22.0	0.1	70	19	16

*As propane

TABLE 3-4. TIRE BURN DATA: SHRED CONDITION DAY 1
Start Time: 13:02:13.99; Run Date: 2-02-1989

Time (min)	O_2 (% [dry])	CO_2 (% [dry])	CO (ppm [dry])	SO_2 (ppm [wet])	*THC (ppm [wet])
0	20.4	0	2	4	2
5	20.4	0	2	4	2
10	20.4	0.1	1	9	2
15	20.5	0	1	3	2
20	20.4	0.1	2	13	10
25	19.6	0.2	149	54	40
30	19.8	0.5	141	51	30
35	20.0	0.4	85	39	15
40	20.1	0.2	77	33	16
45	20.0	0.2	103	38	19
50	20.2	0.2	97	33	18
55	20.2	0.2	85	28	16
60	20.3	0.1	75	24	15
65	20.3	0.1	71	24	16
70	20.3	0.1	64	22	15
75	20.3	0.1	58	16	15
80	20.4	0.1	53	14	15
85	20.4	0.1	52	14	15
90	20.4	0.1	48	15	14
95	20.3	0.1	46	16	14
100	20.3	0.1	43	16	13
105	20.4	0.1	39	15	13
110	20.4	0.1	37	12	13
115	20.4	0.1	33	15	14
120	20.4	0.1	30	16	13
125	20.4	0.1	29	14	13
130	20.4	0.1	29	20	17
135	20.1	0.1	160	41	25
140	20.2	0.2	135	28	16
145	20.3	0.1	107	20	14
150	20.3	0.1	89	20	14
155	20.4	0.1	79	18	14
160	20.4	0.1	67	15	13
165	20.4	0.1	56	15	13
170	20.4	0.1	52	16	16
175	20.4	0.1	42	15	17
180	20.5	0.1	39	15	17
185	20.5	0.1	35	14	14
190	20.5	0.1	34	13	15
195	20.5	0	30	13	14
200	20.5	0	29	15	17
205	20.5	0	25	13	16
210	20.5	0	24	9	14
215	20.6	0	22	6	13
220	20.7	0	22	5	13
225	20.7	0	22	-7	12

*As propane

TABLE 3-5. TIRE BURN DATA: SHRED CONDITION DAY 2
Start Time: 10:40:13.18; Run Date: 2-03-1989

Time (min)	O_2 (% [dry])	CO_2 (% [dry])	CO (ppm [dry])	SO_2 (ppm [wet])	*THC (ppm [wet])
0	22.0	0	0	5	3
5	21.8	0	0	5	3
10	21.9	0	0	2	3
15	21.9	0	0	-1	3
20	21.9	0	1	-2	3
25	21.7	0	48	15	19
30	20.9	0.3	217	62	49
35	21.2	0.4	132	48	30
40	21.5	0.3	74	23	17
45	21.6	0.1	62	11	14
50	21.7	0.1	76	7	14
55	21.7	0.1	89	13	18
70	21.8	0.1	75	17	8
75	21.8	0.1	68	23	17
80	21.9	0	59	28	16
85	21.9	0	52	31	15
90	21.9	0	49	31	15
95	21.9	0	44	26	14
100	22.0	0	40	22	13
105	22.0	0	38	21	13
110	22.0	0	35	21	13
115	22.0	0	33	24	12
120	22.0	0	33	30	12
125	22.0	0	33	29	12
130	21.7	0	106	49	30
135	21.5	0.2	149	76	24
140	21.7	0.2	110	64	16
145	21.8	0.1	99	55	14
150	21.9	0.1	88	50	12
155	21.9	0.1	79	45	11
160	21.9	0.1	68	41	10
165	21.9	0	65	40	11
170	22.0	0	59	36	11
175	22.0	0	57	25	11
180	22.0	0	49	22	10
185	22.0	0	45	26	14
190	22.1	0	42	24	17
195	22.1	0	40	30	14
200	22.1	0	35	24	13
205	22.1	0	30	17	14
210	22.1	0	28	15	13
215	22.1	0	26	15	12
220	22.1	0	25	20	11

*As propane

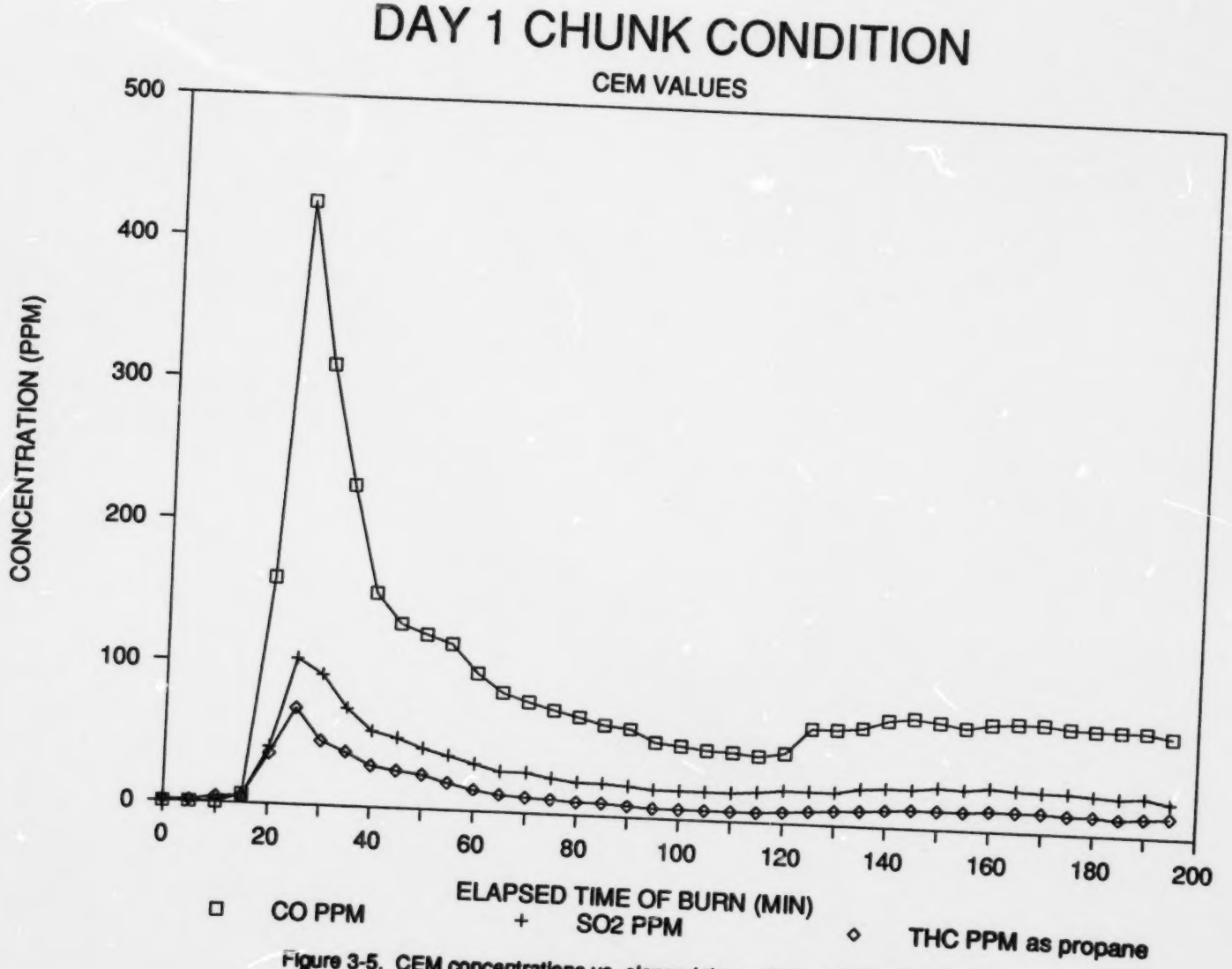

Figure 3-5. CEM concentrations vs. elapsed time—Day 1 "CHUNK" condition.

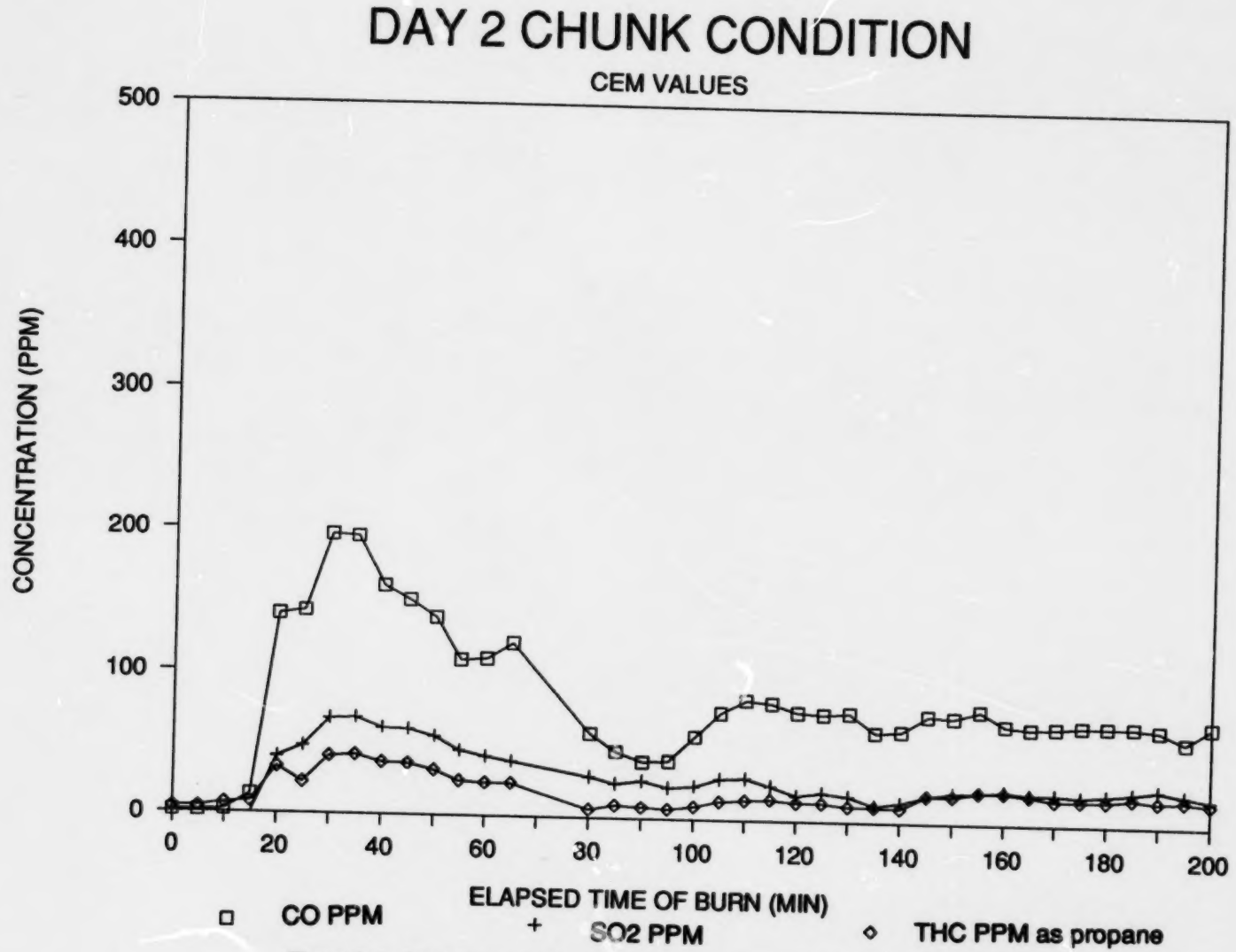

Figure 3-6. CEM concentrations vs. elapsed time—Day 2 "CHUNK" condition.

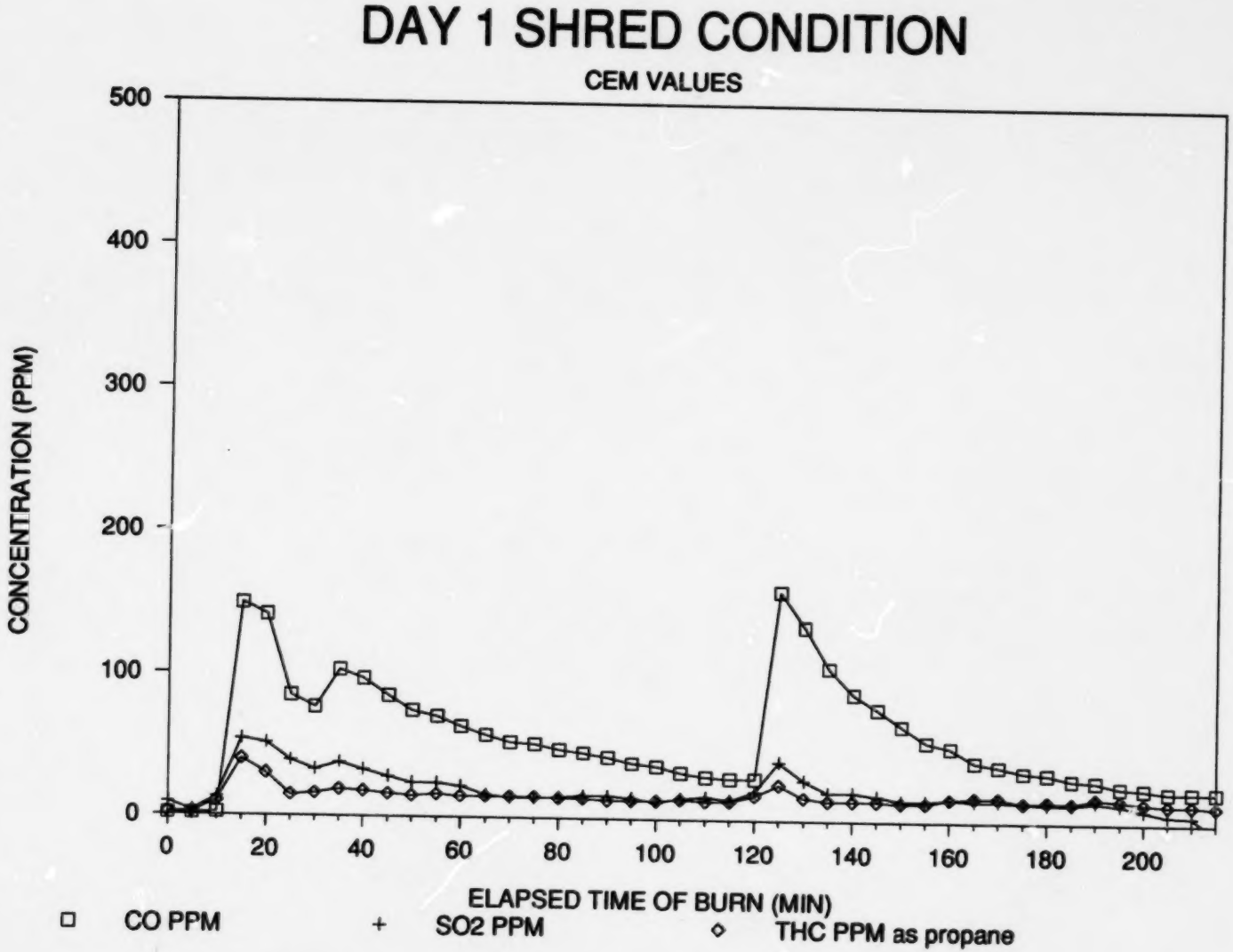

Figure 3-7. CEM concentrations vs. elapsed time--Day 1 "SHRED" condition.

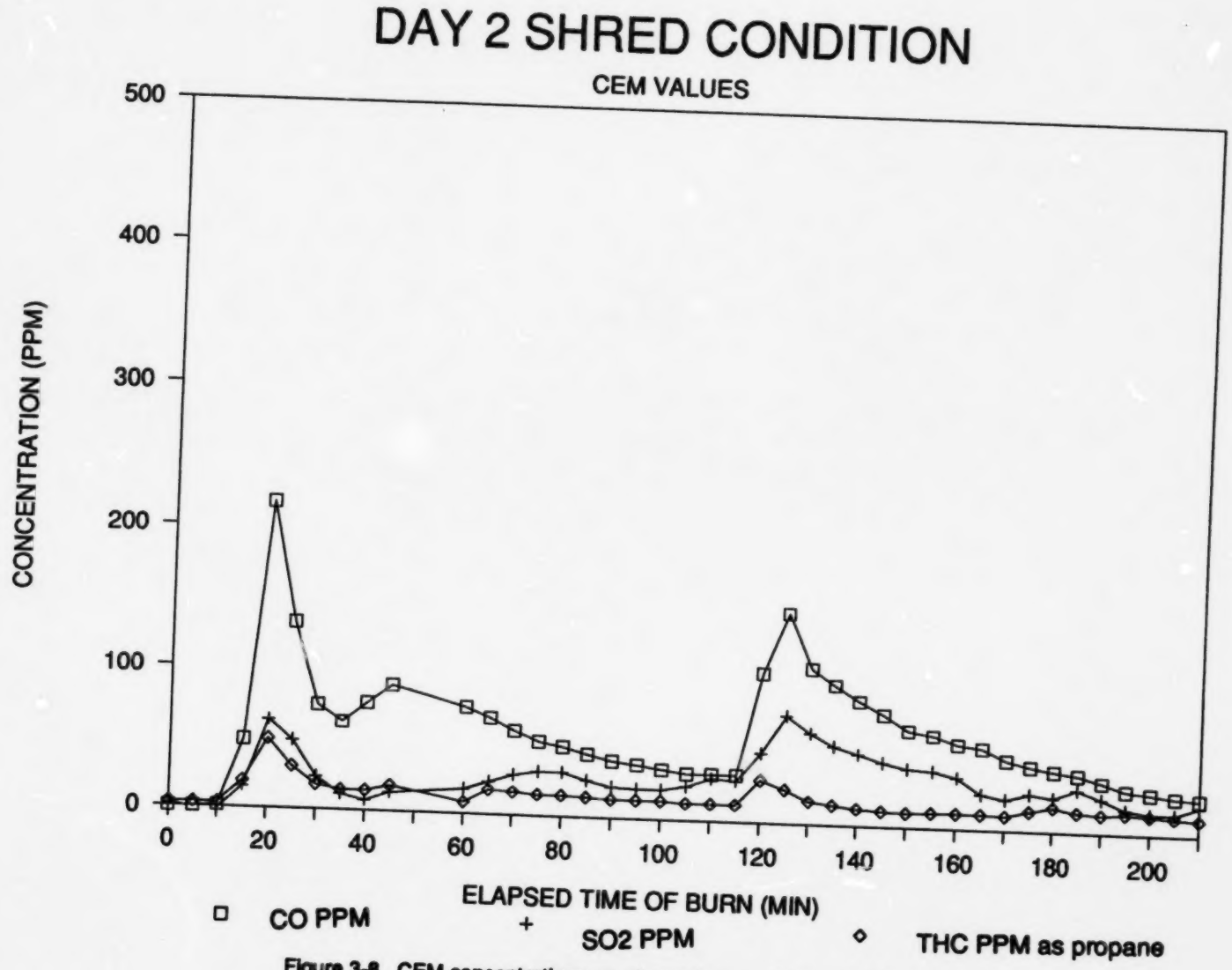

Figure 3-8. CEM concentrations vs. elapsed time—Day 2 "SHRED" condition.

TABLE 3-6. COMPOUNDS IDENTIFIED BY GC/MS FROM VOST RUNS

Compound Identified	Formula
BUTADIENE	C_4H_6
TRICHLOROFLOUROMETHANE	CCl_3F
PENTADIENE	C_5H_8
CYCLOPENTADIENE	C_5H_6
BENZENE	C_6H_6
THIOPHENE	C_4H_4S
ALIPHATIC ALKANE	C_7H_{16}
ALIPHATIC ALKENE	C_7H_{14}
DIENE	C_7H_{12}
METHYL CYCLOHEXENE	C_7H_{12}
METHYL HEXADIENE	C_7H_{12}
HEPTADIENE	C_7H_{12}
METHYL BENZENE	C_7H_8
METHYL THIOPHENE	C_5H_6S
ALIPHATIC ALKANE	C_8H_{18}
ALIPHATIC ALKENE	C_8H_{16}
DIMETHYL HEXADIENE	C_8H_{14}
ETHENYL CYCLOHEXENE	C_8H_{12}
ETHYL BENZENE	C_8H_{10}
DIMETHYL BENZENE	C_8H_{10}
ETHYNYL BENZENE	C_8H_6
ETHENYL BENZENE	C_8H_8
METHYLETHYL BENZENE	C_9H_{12}
CYCLIC ALKENE	$C_{10}H_{16}$
ETHENYLDIMETHYLCYCLOHEZENE	$C_{10}H_{16}$
PROPYL BENZENE	C_9H_{12}
ETHYL,METHYL BENZENE	C_9H_{12}
TRIMETHYL BENZENE	C_9H_{12}
METHYL,ETHENYL BENZENE	C_9H_{10}
BENZALDEHYDE	C_7H_6O
TRIMETHYL BENZENE	C_9H_{12}
ETHENYLMETHYL BENZENE	C_9H_{10}
ETHENYL,METHYL BENZENE	C_9H_{10}
BENZOFURAN	C_8H_6O
METHYL,METHYLETHYL C.H.	$C_{10}H_{18}$
LIMOMENE	$C_{10}H_{16}$
METHYL,METHYLETHYL BENZENE	$C_{10}H_{14}$
ISOCYANO BENZENE	C_7H_5N
DIHYDROINDENE	C_9H_{10}
METHYL,PROPYL BENZENE	$C_{10}H_{14}$
TETRAMETHYL BENZENE	$C_{10}H_{14}$
ETHYNYL,METHYL BENZENE	C_9H_8
PHENOL	C_6H_6O
ALIPHATIC AROMATIC	$C_{10}H_{12}$
METHYL,METHYLETHENYL BENZENE	$C_{10}H_{12}$
ETHENYL,DIMETHYL BENZENE	$C_{10}H_{12}$

(continued)

TABLE 3-6. COMPOUNDS IDENTIFIED BY GC/MS FROM VOST RUNS (concluded)

Compound Identified	Formula
TETRAMETHYL BENZENE	$C_{10}H_{14}$
METHYL INDENE	$C_{10}H_{10}$
METHYLENE INDENE	$C_{10}H_{8}$
DIMETHYLDIHYDRO INDENE	$C_{11}H_{14}$
DIMETHYL,METHYLPROPYL BENZENE	$C_{12}H_{18}$
NAPHTHALENE	$C_{10}H_{8}$
BENZOTHIOPHENE	$C_{8}H_{6}S$
BENZODIAZINE	$C_{8}H_{6}N_{2}$
METHYL NAPHTHALENE	$C_{11}H_{10}$

compound, trichloroflouromethane, was also identified in several of the collected samples. This chloroflourocarbon (CFC), also known as FREON-11, was probably emitted by the air conditioners used to dilute the air in the burn hut. Several sulfonated compounds were identified in the samples. Thiophene and substituted thiophenes were isolated. Nitrogenated hydrocarbons were found. Isocyano benzene and benzodiazine were isolated in multiple samples.

The average gaseous concentration and estimated emissions of identified volatile organics at various burn rates are presented in Tables 3-7 through 3-10. These values are estimates and are calculated using the MS response to toluene.

The data do not reveal consistent trends in either the types or amounts of emissions under varied burn rates. Benzene is emitted in large quantities under both conditions. Average gaseous concentration concentrations increase with increased burn rate, but this is true with the majority of the compounds presented. It is interesting to note, however, that as the burn rate decreased, the amount of specific compounds emitted tended to increase with respect to the amount of tire material combusted. It may be that during the latter portion of the burn period, the remaining rubber in the tire material was bound with the cord material and became difficult to burn. In this lower temperature regime, the rubber continued to be pyrolyzed, but less was combusted while the volatiles reacted to form the types of compounds identified.

The estimated emissions presented are estimations based on several variables. They were obtained by assuming that the dilution air added to the burn hut was at a constant volume and that the amount of air added equaled the amount exiting the hut. It was also assumed that the gas mixture collected in the sample duct was well mixed and representative of the gas mixture found throughout the burn hut. The average gaseous concentration or average concentration of the sample over a given period was determined by dividing the total collected amount (obtained by GC/MS analysis) by the volume of sample collected. This value was then multiplied by the amount of air added to the burn hut in 1 h. This value is the amount of a specific compound emitted on an hourly basis, and it was then divided by the burn rate determined for that period. The burn rate, as outlined earlier, was determined by dividing

TABLE 3-7. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 1 CHUNK CONDITION[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 6.63 kg/h VOL SAMP = 0.01673 m^3		SET 2 BURN RATE = 2.27 kg/h VOL SAMP = 0.02024 m^3		SET 3 BURN RATE = 1.27 kg/h VOL SAMP = 0.02022 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
BUTADIENE	0.136	41.7	0.066	59.1	0.115	185.0
TRICHLOROFLOUROMETHANE	1.003	308.5	0.000	0.0	0.015	23.4
PENTADIENE	0.000	0.0	0.038	34.5	0.092	147.7
CYCLOPENTADIENE	0.273	84.0	0.011	10.1	0.043	68.3
BENZENE	3.872	1190.9	1.159	1041.2	1.316	2113.4
METHYL BENZENE	1.219	375.0	0.332	298.6	0.535	859.3
ETHYL BENZENE	0.099	30.4	0.052	46.8	0.066	106.2
DIMETHYL BENZENE	0.481	147.9	0.124	111.8	0.238	382.4
ETHYNYL BENZENE	0.974	299.5	0.092	83.0	0.105	168.2
ETHENYL BENZENE	1.205	370.6	0.210	188.6	0.489	784.6
METHYLETHYL BENZENE	0.000	0.0	0.008	7.4	0.035	56.7
PROPYL BENZENE	0.010	3.1	0.006	5.3	0.020	32.4
ETHYL,METHYL BENZENE	0.029	9.0	0.020	18.1	0.076	122.6
TRIMETHYL BENZENE	0.012	3.7	0.008	6.7	0.019	30.6
ETHYL,METHYL BENZENE	0.000	0.0	0.000	0.0	0.012	18.5
METHYL,ETHENYL BENZENE	0.025	7.5	0.009	8.4	0.024	38.4
BENZALDEHYDE	0.566	174.0	0.075	67.6	0.129	207.3
ETHENYLMETHYL BENZENE	0.315	96.7	0.020	17.9	0.047	75.6
ETHENYL,METHYL BENZENE	0.000	0.0	0.015	13.5	0.024	37.8
BENZOFURAN	0.169	51.9	0.016	14.4	0.014	22.1
LIMONENE	0.000	0.0	0.000	0.0	0.010	16.5
METHYL,METHYLETHYL BENZENE	0.000	0.0	0.000	0.0	0.014	21.9
ISOCYANO BENZENE	1.330	409.1	0.063	56.2	0.108	172.9
DIHYDROINDENE	0.000	0.0	0.000	0.0	0.010	16.7
ETHYNYL,METHYL BENZENE	1.347	414.4	0.172	154.2	0.249	399.0

(continued)

TABLE 3-7. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 1 CHUNK CONDITION (concluded)[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 6.63 kg/h VOL SAMP = 0.01673 m^3		SET 2 BURN RATE = 2.27 kg/h VOL SAMP = 0.02024 m^3		SET 3 BURN RATE = 1.27 kg/h VOL SAMP = 0.02022 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
METHYL,METHYLETHYL BENZENE	0.000	0.0	0.000	0.0	0.018	29.2
PHENOL	0.011	3.5	0.000	0.0	0.000	0.0
METHYL,METHYLETHENYL BENZENE	0.066	20.2	0.000	0.0	0.036	58.2
ETHENYL,DIMETHYL BENZENE	0.023	7.0	0.000	0.0	0.000	0.0
METHYL INDENE	0.082	25.2	0.014	12.9	0.035	55.9
METHYL INDENE	0.056	17.3	0.014	12.9	0.037	59.7
METHYLENE INDENE	0.074	22.9	0.011	9.6	0.021	32.9
NAPTHALENE	2.953	908.1	0.668	600.2	0.749	1201.9
BENZOTHIOPHENE	0.000	0.0	0.018	16.4	0.011	18.5
BENZODIAZINE	0.033	10.0	0.016	14.3	0.013	21.1
METHYL NAPTHALENE	0.342	105.1	0.077	69.5	0.101	162.0
METHYL NAPTHALENE	0.212	65.1	0.052	47.1	0.068	110.0
TOTALS	16.915	5202.2	3.369	3026.2	4.904	7873.1

1 Concentrations determined using system response to toluene.
2 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-8. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 2 CHUNK CONDITION[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 3.5 kg/h VOL SAMP = 0.0186 m^3		SET 2 BURN RATE = 1.7 kg/h VOL SAMP = 0.02053 m^3		SET 3 BURN RATE = .5 kg/h VOL SAMP = 0.02015 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
BUTADIENE	0.135	78.6	0.147	175.8	0.314	1279.0
TRICHLOROFLOUROMETHANE	0.057	33.3	0.000	0.0	0.000	0.0
PENTADIENE	0.037	21.8	0.134	161.2	0.146	597.0
CYCLOPENTADIENE	0.164	95.3	0.034	40.9	0.000	0.0
BENZENE	2.970	1730.3	1.272	1525.5	1.290	5262.5
THIOPHENE	0.042	24.6	0.030	35.8	0.064	261.8
METHYL CYCLOHEXENE	0.000	0.0	0.000	0.0	0.030	124.2
METHYL HEXADIENE	0.000	0.0	0.026	31.7	0.095	387.0
HEPTADIENE	0.000	0.0	0.019	22.6	0.031	126.2
METHYL BENZENE	1.556	906.7	0.855	1025.7	1.486	6060.3
METHYL THIOPHENE	0.014	8.0	0.020	24.5	0.000	0.0
DIMETHYL HEXADIENE	0.000	0.0	0.011	13.0	0.038	153.3
ETHENYL CYCLOHEXENE	0.000	0.0	0.000	0.0	0.038	153.9
ETHYL BENZENE	0.088	51.2	0.239	287.2	0.537	2189.6
DIMETHYL BENZENE	0.506	295.0	0.379	454.7	0.789	3219.4
ETHYNYL BENZENE	0.804	468.6	0.095	113.6	0.010	40.6
ETHENYL BENZENE	1.054	614.2	0.495	593.2	0.748	3051.1
METHYLETHYL BENZENE	0.000	0.0	0.059	70.3	0.161	657.9
PROPYL BENZENE	0.000	0.0	0.029	35.2	0.086	349.7
ETHYL,METHYL BENZENE	0.032	18.6	0.121	145.5	0.338	1378.9
TRIMETHYL BENZENE	0.017	9.9	0.026	30.9	0.048	194.2
ETHYL,METHYL BENZENE	0.000	0.0	0.020	23.9	0.057	231.9
METHYL,ETHENYL BENZENE	0.030	17.6	0.019	23.2	0.057	234.1
BENZALDEHYDE	0.497	289.8	0.154	184.7	0.213	868.1
ETHENYLMETHYL BENZENE	0.083	48.6	0.106	126.6	0.232	947.2

(continued)

TABLE 3-8. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 2 CHUNK CONDITION (concluded)[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 3.5 kg/h VOL SAMP = 0.0186 m^3 AVERAGE GASEOUS CONCENTRATION (mg/m^3)	SET 1 ESTIMATED EMISSIONS (mg/kg TIRE)	SET 2 BURN RATE = 1.7 kg/h VOL SAMP = 0.02053 m^3 AVERAGE GASEOUS CONCENTRATION (mg/m^3)	SET 2 ESTIMATED EMISSIONS (mg/kg TIRE)	SET 3 BURN RATE = .5 kg/h VOL SAMP = 0.02015 m^3 AVERAGE GASEOUS CONCENTRATION (mg/m^3)	SET 3 ESTIMATED EMISSIONS (mg/kg TIRE)
ETHENYL,METHYL BENZENE	0.059	34.1	0.000	0.0	0.000	0.0
BENZOFURAN	0.118	68.5	0.000	0.0	0.000	0.0
LIMONENE	0.000	0.0	0.024	28.6	0.028	116.1
METHYL,METHYLETHYL BENZENE	0.000	0.0	0.058	70.0	0.053	215.7
ISOCYANO BENZENE	0.308	179.5	0.126	151.6	0.274	1116.1
DIHYDROINDENE	0.000	0.0	0.016	19.7	0.050	202.3
METHYL,PROPYL BENZENZE	0.000	0.0	0.000	0.0	0.000	0.0
ETHYNYL,METHYL BENZENE	1.288	750.4	0.219	263.0	0.300	1223.0
METHYL,METHYLETHYL BENZENE	0.000	0.0	0.026	31.8	0.070	285.2
METHYL,METHYLETHENYL BENZENE	0.012	7.2	0.059	71.3	0.103	420.4
ETHENYL,DIMETHYL BENZENE	0.067	38.9	0.000	0.0	0.000	0.0
METHYL INDENE	0.085	49.5	0.037	44.8	0.136	554.6
METHYL INDENE	0.062	36.2	0.050	59.6	0.231	940.1
METHYLENE INDENE	0.074	42.8	0.018	21.7	0.039	159.9
DIMETHYLDIHYDRO INDENE	0.000	0.0	0.010	12.4	0.029	117.1
NAPTHALENE	2.602	1515.8	0.707	848.2	0.425	1733.6
BENZOTHIOPHENE	0.000	0.0	0.030	36.0	0.020	82.3
BENZODIAZINE	0.020	11.7	0.020	24.5	0.000	0.0
METHYL NAPTHALENE	0.372	216.6	0.104	124.9	0.131	533.9
METHYL NAPTHALENE	0.212	123.3	0.067	79.8	0.056	228.5
TOTALS	13.366	7786.7	5.864	7033.8	8.753	35696.7

1 Concentrations determined using system response to toluene.
2 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-9. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 1 SHRED CONDITION[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 1.3 kg/h VOL SAMP = 0.02225 m^3		SET 2 BURN RATE = 1.4 kg/h VOL SAMP = 0.02043 m^3		SET 3 BURN RATE = .8 kg/h VOL. SAMP = 0.01896 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
BUTADIENE	0.134	210.7	0.141	204.6	0.000	0.0
PENTADIENE	0.784	1229.8	0.697	1015.1	0.980	2498.1
BENZENE	1.271	1992.9	1.616	2353.4	1.117	2847.9
THIOPHENE	0.037	58.0	0.025	36.1	0.000	0.0
METHYL CYCLOHEXENE	0.025	39.6	0.018	26.6	0.030	75.8
METHYL HEXADIENE	0.054	84.2	0.043	63.2	0.117	298.9
HEPTADIENE	0.000	0.0	0.021	30.0	0.044	112.5
METHYL BENZENE	0.637	998.8	0.650	946.5	0.625	1592.6
METHYL THIOPHENE	0.020	31.9	0.000	0.0	0.000	0.0
DIMETHYL HEXADIENE	0.061	95.0	0.020	29.2	0.083	211.1
ETHENYL CYCLOHEXENE	0.063	98.6	0.000	0.0	0.089	226.0
ETHYL BENZENE	0.130	204.4	0.066	95.7	0.263	670.7
DIMETHYL BENZENE	0.679	1065.1	0.713	1038.9	0.771	1966.2
ETHYNYL BENZENE	0.087	136.4	0.174	253.4	0.000	0.0
ETHENYL BENZENE	0.345	540.5	0.435	632.9	0.332	845.3
METHYLETHYL BENZENE	0.095	148.2	0.073	105.7	0.163	415.7
ETHENYLDIMETHYLCYCLOHEXENE	0.243	380.8	0.195	284.4	0.341	869.6
PROPYL BENZENE	0.037	58.3	0.051	74.3	0.084	212.9
ETHYL,METHYL BENZENE	0.223	350.3	0.227	331.2	0.349	889.7
TRIMETHYL BENZENE	0.041	63.9	0.034	49.1	0.062	157.5
ETHYL,METHYL BENZENE	0.038	59.8	0.036	52.4	0.065	164.8
METHYL,ETHENYL BENZENE	0.040	63.2	0.043	62.4	0.063	159.8
BENZALDEHYDE	0.201	314.7	0.195	283.4	0.172	439.5
ETHENYLMETHYL BENZENE	0.037	58.0	0.024	35.1	0.026	67.5

(continued)

TABLE 3-9. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN VOST SAMPLES: DAY 1 SHRED CONDITION (concluded)[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 1.3 kg/h VOL SAMP = 0.02225 m^3		SET 2 BURN RATE = 1.4 kg/h VOL SAMP = 0.02043 m^3		SET 3 BURN RATE = .8 kg/h VOL. SAMP = 0.01896 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
ETHENYL,METHYL BENZENE	0.000	0.0	0.012	18.1	0.016	40.5
METHYL,METHYLETHYL C.H.	0.080	126.0	0.080	116.2	0.180	458.8
LIMONENE	0.379	595.2	0.502	731.4	0.760	1936.1
METHYL,METHYLETHYL BENZENE	0.082	128.7	0.091	132.2	0.056	143.9
ISOCYANO BENZENE	0.312	489.3	0.143	208.4	0.080	203.6
DIHYDROINDENE	0.022	34.4	0.024	35.3	0.045	115.1
METHYL,PROPYL BENZENZE	0.031	48.2	0.019	27.7	0.045	114.2
TETRAMETHYL BENZENE	0.204	320.3	0.000	0.0	0.169	430.7
ETHYNYL,METHYL BENZENE	0.000	0.0	0.405	590.3	0.000	0.0
METHYL,METHYLETHYL BENZENE	0.067	104.8	0.071	103.6	0.126	320.4
METHYL,METHYLETHENYL BENZENE	0.424	664.7	0.411	598.9	0.649	1655.3
ETHENYL,DIMETHYL BENZENE	0.000	0.0	0.000	0.0	0.018	46.2
TETRAMETHYL BENZENE	0.043	68.0	0.036	51.8	0.076	194.9
METHYL INDENE	0.000	0.0	0.027	39.3	0.027	68.5
METHYL INDENE	0.050	79.0	0.053	77.7	0.071	180.7
METHYLENE INDENE	0.015	23.6	0.019	27.6	0.023	57.8
DIMETHYLDIHYDRO INDENE	0.000	0.0	0.013	18.3	0.021	54.3
DIMETHYL,METHYLPROPYL BENZENE	0.014	22.1	0.013	18.9	0.020	50.9
NAPTHALENE	0.458	718.0	0.889	1295.4	0.224	571.4
BENZOTHIOPHENE	0.007	11.1	0.019	27.9	0.000	0.0
BENZODIAZINE	0.016	24.6	0.018	25.6	0.000	0.0
METHYL NAPTHALENE	0.057	88.8	0.112	163.2	0.067	170.5
METHYL NAPTHALENE	0.041	64.6	0.063	91.6	0.043	110.8
TOTALS	7.583	11894.4	8.516	12403.2	8.493	21646.6

1 Concentrations determined using system response to toluene.
2 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-10. QUANTITATION AND EMISSION SUMMARY OF COMPOUND IDENTIFIED IN VOST SAMPLE: DAY 2 SHRED CONDITION[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 1.5 kg/h VOL SAMP = 0.01912 m^3		SET 2 BURN RATE = 2.3 kg/h VOL SAMP = 0.01946 m^3		SET 3 BURN RATE = .9 kg/h VOL SAMP = 0.0213 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
BUTADIENE	0.077	104.7	0.044	38.7	0.163	370.2
PENTADIENE	0.956	1298.9	0.399	353.8	0.306	693.6
BENZENE	1.509	2051.2	1.882	1668.8	1.039	2352.8
THIOPHENE	0.032	43.3	0.031	27.8	0.000	0.0
METHYL CYCLOHEXENE	0.020	26.7	0.016	14.0	0.026	58.4
METHYL HEXADIENE	0.067	91.2	0.045	39.5	0.066	194.6
HEPTADIENE	0.043	58.6	0.019	17.3	0.042	95.2
METHYL BENZENE	0.692	940.2	1.112	985.9	0.587	1330.8
METHYL THIOPHENE	0.010	14.3	0.000	0.0	0.011	25.9
DIMETHYL HEXADIENE	0.047	63.7	0.029	25.3	0.055	124.7
ETHENYL CYCLOHEXENE	0.084	114.8	0.051	44.9	0.073	165.4
ETHYL BENZENE	0.209	283.7	0.149	131.7	0.180	407.4
DIMETHYL BENZENE	0.543	737.8	0.543	481.2	0.535	1211.1
ETHYNYL BENZENE	0.094	128.4	0.308	273.2	0.000	0.0
ETHENYL BENZENE	0.470	638.8	0.569	504.2	0.236	534.5
METHYLETHYL BENZENE	0.081	110.7	0.051	45.4	0.090	203.0
CYCLIC ALKENE	0.074	100.5	0.034	30.2	0.056	127.3
ETHENYLDIMETHYLCYCLOHEXENE	0.213	289.9	0.065	57.6	0.112	253.9
PROPYL BENZENE	0.047	64.1	0.024	20.9	0.037	84.5
ETHYL,METHYL BENZENE	0.224	304.7	0.157	139.5	0.260	589.1
TRIMETHYL BENZENE	0.037	51.0	0.034	29.8	0.045	101.1
METHYL,ETHENYL BENZENE	0.057	77.6	0.035	30.9	0.032	72.2
BENZALDEHYDE	0.210	285.2	0.369	327.3	0.148	334.7
ETHENYLMETHYL BENZENE	0.035	47.8	0.046	40.5	0.000	0.0

(continued)

TABLE 3-10. QUANTITATION AND EMISSION SUMMARY OF COMPOUND IDENTIFIED IN VOST SAMPLE: DAY 2 SHRED CONDITION (concluded)[1,2]

COMPOUND IDENTIFIED	SET 1 BURN RATE = 1.5 kg/h VOL SAMP = 0.01912 m^3		SET 2 BURN RATE = 2.3 kg/h VOL SAMP = 0.01946 m^3		SET 3 BURN RATE = .9 kg/h VOL SAMP = 0.0213 m^3	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
ETHENYL,METHYL BENZENE	0.022	30.5	0.038	33.4	0.000	0.0
METHYL,METHYLETHYL C.H.	0.080	108.5	0.000	0.0	0.100	225.6
LIMONENE	0.631	858.4	0.433	384.1	0.414	936.8
METHYL,METHYLETHYL BENZENE	0.060	81.0	0.122	108.2	0.118	266.4
ISOCYANO BENZENE	0.155	210.3	0.292	259.1	0.149	336.8
DIHYDROINDENE	0.000	0.0	0.000	0.0	0.032	73.4
METHYL,PROPYL BENZENZE	0.000	0.0	0.000	0.0	0.027	60.4
TETRAMETHYL BENZENE	0.000	0.0	0.000	0.0	0.116	263.5
ETHYNYL,METHYL BENZENE	0.264	358.3	0.720	637.9	0.000	0.0
METHYL,METHYLETHYL BENZENE	0.074	100.9	0.047	42.1	0.074	168.6
PHENOL	0.000	0.0	0.099	87.9	0.000	0.0
METHYL,METHYLETHENYL BENZENE	0.376	511.2	0.121	107.1	0.275	622.1
ETHENYL,DIMETHYL BENZENE	0.023	31.1	0.025	22.0	0.020	45.4
TETRAMETHYL BENZENE	0.039	53.6	0.037	33.1	0.050	112.3
METHYL INDENE	0.033	45.0	0.062	55.0	0.024	55.3
METHYL INDENE	0.066	89.5	0.072	63.5	0.044	98.9
METHYLENE INDENE	0.022	29.5	0.040	35.4	0.015	35.1
DIMETHYLDIHYDRO INDENE	0.000	0.0	0.000	0.0	0.016	36.6
NAPTHALENE	0.661	899.1	1.294	1147.1	0.153	345.8
BENZOTHIOPHENE	0.024	32.2	0.020	17.9	0.000	0.0
BENZODIAZINE	0.017	22.9	0.035	31.4	0.000	0.0
METHYL NAPTHALENE	0.080	108.9	0.164	145.0	0.013	30.6
METHYL NAPTHALENE	0.088	120.2	0.084	74.4	0.014	32.0
TOTALS	8.547	11618.2	9.715	8613.0	5.771	13074.8

1 Concentrations determined using system response to toluene.

2 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

the amount of tire material combusted in a specific period by that amount of time (in minutes) and normalizing it to an hourly basis. The resultant value is an emission estimate of the amount of compound emitted at a specific burn rate. An example calculation follows:

> The amount of ethenyl benzene (styrene) found to be in the first sample collected on the second day of the "CHUNK" condition was determined to be 0.01961 mg. The sample represented 0.0186 m^3 of gas stream collected over a 42.1 min continuous period. During this time, 5.4 lb of tire material were consumed through combustion. The volume of air introduced into the burn hut equalled 1,200 cfm. This equals 2,039 m^3/h.
>
> The average gaseous concentration = 0.01961 mg/0.0186 m^3 = 1.054 mg/m^3
>
> The burn rate = (5.4 lb/42.1 min) (60 min/h) = 7.7 lb/h = 3.5 kg/h
>
> The estimated emissions = (1.054 mg/m^3) (2039 m^3/h)/ 3.5 kg/h = 614.0 mg of styrene/kg of tire combusted.

3.4 SEMI-VOLATILE ORGANICS

As with the volatile organic analyses, the MS analysis of the XAD-2 extracts produced the identification of the same types of compounds. Table 3-11 lists the 60 compounds identified and indicates that substituted mono- and poly-aromatics were again the predominant products of incomplete combustion. Many of the compounds collected and identified by the VOST technique were also found in the XAD-2 extracts. Table 3-12 shows that similar ambient-loading and emission-rate values were realized from the XAD-2 extracts. The emission rate for many compounds increased with decreasing burn rate, but not for all. The emission of napthalene, for example, was much greater at higher burn rates, as evidenced during the "CHUNK" condition. In addition, the average gaseous concentration is also greater in this situation. This finding contrasts with the trends observed in the VOST samples.

The particulate filters located upstream of the XAD-2 canisters contained considerable quantities of organics. The majority of compounds found in the particulate have boiling points exceeding 300 °C. Table 3-13 contains a summary of semi-volatile organic emission data from all 4 test conditions. The total organics from respective boiling-point-based analyses are presented for each component of the sampling media. The emission rate data presented show that from 12-50 g of semi-volatile organics can be emitted for every kilogram of tire burned. It appears that as burn rate decreased, the amount of organics

TABLE 3-11. COMPOUNDS IDENTIFIED BY GC/MS FROM XAD-2 EXTRACTS

Compound Identified	Formula
METHYL BENZENE	C_7H_8
CYCLOPENTANONE	C_5H_8
DIMETHYL CYCLOHEXENE	C_8H_{12}
ETHENYL CYCLOHEXENE	C_8H_{12}
ETHYL BENZENE	C_8H_{10}
DIMETHYL BENZENE	C_8H_{10}
HEXANENITRILE	$C_6H_{11}N$
ETHYNYL BENZENE	C_8H_6
STYRENE	C_8H_8
NONANE	C_9H_{20}
PROPENYL CYCLOHEXANE	C_9H_{16}
METHYLETHYL BENZENE	C_9H_{12}
PROPYL BENZENE	C_9H_{12}
BENZALDEHYDE	C_7H_6O
TRIMETHYL BENZENE	C_9H_{12}
PHENOL	C_6H_6O
CYANOBENZENE	C_7H_5N
PROPENYL BENZENE	C_9H_{10}
METHYL,ETHENYL BENZENE	C_9H_{10}
METHYL,METHYLETHYL BENZENE	$C_{10}H_{14}$
LIMONENE	$C_{10}H_{16}$
DIHYDRO INDENE	C_9H_{10}
HYDROXY BENZALDEHYDE	$C_7H_6O_2$
INDENE	C_9H_8
TETRAMETHYL BENZENE	$C_{10}H_{14}$
ETHYL,DIMETHYL BENZENE	$C_{10}H_{14}$
METHYL PHENOL	C_7H_8O
METHYL BENZALDEHYDE	C_8H_8O
METHYL,(METHYLETHYL) BENZENE	$C_{10}H_{14}$
PROPENYL,METHYL BENZENE	$C_{10}H_{12}$
UNDECANE	$C_{11}H_{24}$
(DIMETHYLPROPYL) BENZENE	$C_{11}H_{16}$
DIMETHYL,(METHYLETHYL) BENZENE	$C_{11}H_{16}$
BUTYNYL BENZENE	$C_{10}H_{12}$
METHYL INDENE	$C_{10}H_{10}$
AZULENE	$C_{10}H_8$
NAPHTHALENE	$C_{10}H_8$
BENZO[B]THIOPHENE	C_8H_6S
BENZISOTHIAZOLE	C_7H_5NS
HEXAHYDRO AZEPINONE	$C_6H_{11}NO$
DIHYDRO,METHYL NAPHTHALENE	$C_{11}H_{12}$
BUTYL,TRIMETHYL BENZENE	$C_{13}H_{20}$
METHYL NAPHTHALENE	$C_{11}H_{10}$
BIPHENYL	$C_{12}H_{10}$
DIMETHYL NAPHTHALENE	$C_{12}H_{12}$
DIHYDRO ACENAPHTHALENE	$C_{12}H_{10}$

(continued)

TABLE 3-11. COMPOUNDS IDENTIFIED BY GC/MS FROM XAD-2 EXTRACTS (concluded)

Compound Identified	Formula
ACENAPHTHALENE	$C_{12}H_8$
(DIMETHYL,HEXENYL),METHYL BENZENE	$C_{14}H_{20}$
PENTADECANE	$C_{15}H_{32}$
1,1' BIPHENYL, METHYL	$C_{13}H_{12}$
ISOCYANO NAPHTHALENE	$C_{11}H_7N$
NAPHTHALENECARBOXALDEHYDE	$C_{11}H_8O$
PROPENYL NAPHTHALENE	$C_{13}H_{12}$
TRIMETHYL NAPHTHALENE	$C_{13}H_{14}$
1H FLUORENE	$C_{13}H_{10}$
DIMETHYL BIPHENYL	$C_{14}H_{14}$
DIBENZOTHIOPHENE	$C_{12}H_{10}S$
PHENANTHRENE	$C_{14}H_{10}$
9H FLUORENE, METHYLENE	$C_{14}H_{10}$
PHENYLNAPHTHALENE	$C_{16}H_{12}$

TABLE 3-12. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN XAD-2 EXTRACTS[1,2]

COMPOUND IDENTIFIED	DAY 1 CHUNK CONDITION VOL SAMP = 12.98 m^3 BURN RATE = 2.3 kg/h		DAY 2 CHUNK CONDITION VOL SAMP = 12.76 mg/m^3 BURN RATE = 1.7 kg/h		DAY 1 SHRED CONDITION VOL SAMP = 13.77 mg/m^3 BURN RATE = 1.1 kg/h		DAY 2 SHRED CONDITION VOL SAMP = 12.43 mg/m^3 BURN RATE = 1.3 kg/h	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
METHYL BENZENE	0.716	634.8	1.500	1799.5	0.731	1354.9	0.911	1429.0
ETHYL BENZENE	0.074	65.8	0.289	347.1	0.192	355.0	0.203	318.3
DIMETHYL BENZENE	0.000	0.0	0.513	615.3	0.554	1026.1	0.532	834.2
ETHYNYL BENZENE	0.185	163.6	0.325	390.0	0.078	144.2	0.150	235.2
STYRENE	0.419	371.5	0.795	953.3	0.332	614.6	0.433	679.8
METHYLETHYL BENZENE	0.000	0.0	0.081	97.4	0.142	263.5	0.122	191.0
PROPYL BENZENE	0.000	0.0	0.000	0.0	0.136	251.2	0.118	184.6
BENZALDEHYDE	0.111	98.6	0.327	392.1	0.343	635.3	0.000	0.0
TRIMETHYL BENZENE	0.000	0.0	0.000	0.0	0.156	289.9	0.351	549.9
PHENOL	0.190	168.3	0.473	566.9	0.360	667.2	0.470	736.8
CYANOBENZENE	0.095	84.3	0.305	365.5	0.307	569.3	0.292	458.6
TRIMETHYL BENZENE	0.127	112.8	0.256	307.6	0.195	361.5	0.199	312.2
METHYL,METHYLETHYL BENZENE	0.000	0.0	0.215	258.1	0.926	1716.1	0.704	1104.9
LIMONENE	0.000	0.0	0.094	113.2	1.402	2599.2	1.316	2064.5
INDENE	0.325	288.5	0.602	722.0	0.156	289.9	0.251	393.9
TETRAMETHYL BENZENE	0.000	0.0	0.000	0.0	0.094	174.8	0.000	0.0
ETHYL,DIMETHYL BENZENE	0.000	0.0	0.000	0.0	0.000	0.0	0.154	241.8
METHYL BENZALDEHYDE	0.000	0.0	0.000	0.0	0.089	164.7	0.000	0.0
ETHYL,DIMETHYL BENZENE	0.000	0.0	0.000	0.0	0.162	300.0	0.000	0.0
PROPENYL,METHYL BENZENE	0.000	0.0	0.000	0.0	0.537	996.2	0.000	0.0
METHYL INDENE	0.000	0.0	0.188	225.6	0.223	413.7	0.114	179.2
METHYL INDENE	0.000	0.0	0.000	0.0	0.000	0.0	0.132	207.3
NAPHTHALENE	1.230	1090.4	1.931	2315.9	0.516	957.2	0.843	1322.8
BENZO[B]THIOPHENE	0.099	87.6	0.000	0.0	0.000	0.0	0.000	0.0
BENZISOTHIAZOLE	0.000	0.0	0.000	0.0	0.179	330.9	0.000	0.0
HEXAHYDRO AZEPINONE	0.000	0.0	0.126	151.4	0.345	638.9	0.555	869.9

(continued)

TABLE 3-12. QUANTITATION AND EMISSION SUMMARY OF COMPOUNDS IDENTIFIED IN XAD-2 EXTRACTS (concluded)[1,2]

	DAY 1 CHUNK CONDITION VOL SAMP = 12.98 m^3 BURN RATE = 2.3 kg/h		DAY 2 CHUNK CONDITION VOL SAMP = 12.76 mg/m^3 BURN RATE = 1.7 kg/h		DAY 1 SHRED CONDITION VOL SAMP = 13.77 mg/m^3 BURN RATE = 1.1 kg/h		DAY 2 SHRED CONDITION VOL SAMP = 12.43 mg/m^3 BURN RATE = 1.3 kg/h	
COMPOUND IDENTIFIED	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
2-METHYL NAPHTHALENE	0.164	145.6	0.466	559.4	0.202	373.9	0.313	490.5
1-METHYL NAPHTHALENE	0.124	109.9	0.463	555.3	0.122	225.7	0.146	229.7
BIPHENYL	0.083	73.5	0.290	347.8	0.180	333.6	0.208	326.3
DIMETHYL NAPHTHALENE	0.000	0.0	0.069	83.0	0.183	338.8	0.000	0.0
ACENAPHTHALENE	0.390	345.6	0.773	927.0	0.217	402.2	0.430	673.8
1,1' BIPHENYL, METHYL	0.025	22.1	0.000	0.0	0.000	0.0	0.000	0.0
ISOCYANO NAPHTHALENE	0.021	18.7	0.000	0.0	0.000	0.0	0.000	0.0
PROPENYL NAPHTHALENE	0.053	46.6	0.000	0.0	0.000	0.0	0.000	0.0
TRIMETHYL NAPHTHALENE	0.000	0.0	0.000	0.0	0.169	312.9	0.203	319.1
1H FLUORENE	0.087	76.9	0.288	346.0	0.141	260.8	0.230	361.2
PHENANTHRENE	0.152	135.0	0.194	233.2	0.000	0.0	0.251	394.2
TOTALS	4.670	4140.4	12672.8	9.367	17362.2	9.633	15108.7	10.566

1 Concentrations determined using system response to TCO calibration mix.
2 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-13. ORGANIC EMISSION SUMMARY

SAMPLE PORTION	SAMPLE TIME (min)	WEIGHT CHANGE (kg)	AVG BURN RATE (kg/h)	VOLUME SAMP (m^3)	AVERAGE GASEOUS CONCENTRATION TCO (mg/m^3)	GRAV (mg/m^3)	ESTIMATED EMISSIONS TCO (mg/kg TIRE)	GRAV	
				DAY 1 CHUNK CONDITION					
XAD-2	140	5.4	2.3	12.98	6.067	0.698	5379	619	
FILTER 1	11	1.7	9.4	0.93	0.043	33.634	9	7296	
FILTER 2	129	3.7	1.7	12.05	0.066	4.823	79	5785	
FILTER TOTAL	140	5.4	2.3	12.98	0.065	6.888	58	6106	
						TOTAL	5436	6725	12161
				DAY 2 CHUNK CONDITION					
XAD-2	152	4.3	1.7	12.76	11.398	0.749	13671	898	
FILTER 1	42	2.4	3.5	3.3	0.018	18.498	11	10776	
FILTER 2	110	1.8	1.0	9.45	0.53	10.219	1081	20837	
FILTER TOTAL	152	4.3	1.7	12.76	0.398	12.359	477	14824	
						TOTAL	14148	15722	29870
				DAY 1 SHRED CONDITION					
XAD-2	182	3.2	1.1	13.77	20.658	0.89	38292	1650	
FILTER	182	3.2	1.1	13.77	0.141	6.822	261	12646	
						TOTAL	38554	14295	52849
				DAY 2 SHRED CONDITION					
XAD-2	183	4.0	1.3	12.43	15.65	1.099	24546	1724	
FILTER	183	4.0	1.3	12.43	0.173	8.771	271	13757	
						TOTAL	24818	15481	40299

emitted, particularly in the TCO range, increased. There did not seem to be any significant variation in GRAV range organic emissions when related to burn rate.

A polycyclic aromatic hydrocarbon (PAH) analysis was performed on the liquid extractions of the XAD-2 and filter components. The results of the analyses are presented in Tables 3-14 through 3-17. The list of 16 PAHs contain several compounds known to be carcinogenic. In particular, the presence of benzo(a)pyrene (BAP) is of major importance. It is a highly scrutinized compound when evaluating combustion processes. Although no trend in concentration related to burn rate exists, the magnitude of the emissions warrants concern.

The PAH analysis reveals that only roughly 10 percent of the GRAV range organics could be accounted for. It was not possible to identify the remaining portion because of equipment limitations. The GC/MS system used was not set up for high temperature applications, so this area remains unexplored. It may be possible that carbon black, a major constituent of tire material, may exist as sub .45 μm particles that passed through the filter during cleanup of the particulate extraction. It may also be possible that some of the discrepancy between the PAH and GRAV results may be due to suspected low sample recoveries for the PAH analysis.

3.5 PARTICULATE LOADING

The collection of particulate was performed using three separate systems. Particulate was captured with the semi-volatile organic system, with the airborne metals particulate collection system, and with a medium volume PM_{10} sampler located in the burn hut. Table 3-18 contains a summary of the particulate loading values of these three systems for the 4 test conditions. For total average gaseous concentration there seems to be good agreement between the organic particulate and the metals particulate systems during each test condition. Moreover, average gaseous concentration increased with increased burn rate. As the burn rate decreased, the percent of organics extracted increased. This finding is important because, although under reduced average gaseous concentration, the amount of organic material that the particulate contains is greater. Comparing burn rate to particulate estimated emissions shows that the emission rate of particulate decreased with lower burn rates, although nearly 100 g of particulate were emitted for every kilogram of tire combusted.

TABLE 3-14. PAH QUANTITATION AND EMISSION SUMMARY: DAY 1 CHUNK CONDITION[1]

COMPOUND IDENTIFIED	XAD-2 EXTRACT VOL SAMP = 12.98 m^3 BURN RATE = 2.3 kg/h		1ST PART FILTER VOL SAMP = 0.93 m^3 BURN RATE = 9.4 kg/h		2ND PART FILTER VOL SAMP = 12.05 m^3 BURN RATE = 1.7 kg/h		FILTER TOTALS VOL. SAMP = 12.98 m^3 BURN RATE = 2.3 kg/h	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
NAPHTHALENE	0.810	718.2	0.000	0.0	0.000	0.0	0.000	0.0
ACENAPHTHYLENE	0.628	556.5	0.000	0.0	0.017	19.9	0.015	13.7
ACENAPHTHENE	0.120	106.4	1.027	222.7	0.114	137.0	0.180	159.2
FLOURENE	0.185	163.9	0.059	12.8	0.007	9.0	0.011	9.9
PHENANTHRENE	0.157	139.5	0.099	21.6	0.045	54.3	0.049	43.6
ANTHRACENE	0.027	24.2	0.000	0.0	0.015	17.5	0.014	12.0
FLOURANTHENE	0.076	67.3	0.473	102.6	0.224	268.7	0.242	214.5
PYRENE	0.000	0.0	0.124	26.8	0.000	0.0	0.009	7.9
BENZ(A)ANTHRACENE	0.001	0.5	0.226	49.0	0.041	48.8	0.054	47.8
CHRYSENE	0.000	0.0	0.368	79.9	0.038	45.4	0.062	54.5
BENZO(B)FLOURANTHENE	0.000	0.0	0.344	74.6	0.025	29.9	0.048	42.3
BENZO(K)FLOURANTHENE	0.000	0.0	0.328	71.1	0.027	32.8	0.049	43.4
BENZO(A)PYRENE	0.000	0.0	0.481	104.4	0.034	40.8	0.066	58.6
DIBENZ(A,H)ANTHRACENE	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0
BENZO(G,H,I)PERYLENE	0.000	0.0	0.441	95.6	0.000	0.0	0.032	28.0
INDENO(1,2,3-CD)PYRENE	0.000	0.0	0.312	67.6	0.019	22.5	0.040	35.2
TOTALS	2.004	1776.5	4.282	928.9	0.606	726.6	0.869	770.6

1 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-15. PAH QUANTITATION AND EMISSION SUMMARY: DAY 2 CHUNK CONDITION[1]

COMPOUND IDENTIFIED	XAD-2 EXTRACT VOL SAMP = 12.76 m^3 BURN RATE = 1.7 kg/h		1ST PART FILTER VOL SAMP = 3.30 m^3 BURN RATE = 3.5 kg/h		2ND PART FILTER VOL SAMP = 9.45 m^3 BURN RATE = 1.0 kg/h		FILTER TOTAL VOL SAMP = 12.76 m^3 BURN RATE = 1.7 kg/h	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
NAPHTHALENE	0.759	910.7	0.000	0.0	0.003	6.5	0.002	2.8
ACENAPHTHYLENE	0.897	1075.8	0.056	32.8	0.067	135.6	0.064	76.5
ACENAPHTHENE	0.013	15.2	0.512	298.2	0.159	323.7	0.250	299.7
FLOURENE	0.277	332.1	0.009	5.5	0.014	27.7	0.013	15.0
PHENANTHRENE	0.201	241.3	0.055	31.8	0.038	77.1	0.042	50.5
ANTHRACENE	0.044	52.6	0.017	10.0	0.021	42.2	0.020	23.7
FLOURANTHENE	0.145	173.4	0.380	221.7	0.117	238.9	0.185	222.1
PYRENE	0.000	0.0	0.192	112.0	0.000	0.0	0.050	59.6
BENZ(A)ANTHRACENE	0.001	1.8	0.135	78.5	0.082	166.4	0.095	114.3
CHRYSENE	0.001	0.6	0.131	76.5	0.051	104.8	0.072	86.4
BENZO(B)FLOURANTHENE	0.000	0.0	0.103	60.2	0.073	148.0	0.080	96.5
BENZO(K)FLOURANTHENE	0.000	0.0	0.105	61.0	0.082	166.8	0.088	105.1
BENZO(A)PYRENE	0.000	0.0	0.157	91.6	0.070	142.7	0.093	110.9
DIBENZ(A,H)ANTHRACENE	0.000	0.0	0.007	4.1	0.000	0.0	0.002	2.2
BENZO(G,H,I)PERYLENE	0.000	0.0	0.172	100.2	0.057	115.9	0.087	103.9
INDENO(1,2,3-CD)PYRENE	0.000	0.0	0.108	63.0	0.039	78.9	0.057	67.9
TOTALS	2.337	2803.5	2.140	1246.9	0.871	1775.1	1.198	1437.3

1 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-16. PAH QUANTITATION AND EMISSION SUMMARY: DAY 1 SHRED CONDITION[1]

PAH	XAD-2 EXTRACT VOL SAMP = 13.77 m^3 BURN RATE = 1.1 kg/h		PART FILTER VOL SAMP = 13.77 m^3 BURN RATE = 1.1 kg/h	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
NAPHTHALENE	0.230	427.2	0.000	0.0
ACENAPHTHYLENE	0.262	486.4	0.000	0.0
ACENAPHTHENE	1.588	2943.6	0.120	223.3
FLOURENE	0.081	150.4	0.002	4.1
PHENANTHRENE	0.118	219.0	0.016	30.1
ANTHRACENE	0.021	39.5	0.005	9.3
FLOURANTHENE	0.076	141.4	0.136	251.8
PYRENE	0.000	0.0	0.070	130.2
BENZ(A)ANTHRACENE	0.002	2.9	0.045	83.1
CHRYSENE	0.000	0.0	0.029	52.9
BENZO(B)FLOURANTHENE	0.000	0.0	0.043	79.7
BENZO(K)FLOURANTHENE	0.000	0.0	0.048	89.3
BENZO(A)PYRENE	0.000	0.0	0.053	98.8
DIBENZ(A,H)ANTHRACENE	0.000	0.0	0.000	0.0
BENZO(G,H,I)PERYLENE	0.000	0.0	0.077	142.1
INDENO(1,2,3-CD)PYRENE	0.000	0.0	0.040	74.3
TOTALS	2.379	4410.3	0.685	1269.0

[1] Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-17. PAH QUANTITATION AND EMISSION SUMMARY: DAY 2 SHRED CONDITION[1]

PAH	XAD-2 EXTRACT VOL SAMP = 12.43 m^3 BURN RATE = 1.3 kg/h		PART FILTER VOL SAMP = 12.43 m^3 BURN RATE = 1.3 kg/h	
	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
NAPHTHALENE	0.347	544.7	0.000	0.0
ACENAPHTHYLENE	0.406	637.2	0.000	0.0
ACENAPHTHENE	0.941	1476.3	0.158	248.2
FLOURENE	0.137	214.5	0.003	4.6
PHENANTHRENE	0.143	225.0	0.020	30.8
ANTHRACENE	0.025	39.5	0.007	10.8
FLOURANTHENE	0.133	208.6	0.200	314.1
PYRENE	0.013	20.4	0.097	152.8
BENZ(A)ANTHRACENE	0.008	12.6	0.068	106.1
CHRYSENE	0.001	1.3	0.082	129.0
BENZO(B)FLOURANTHENE	0.000	0.0	0.062	97.0
BENZO(K)FLOURANTHENE	0.000	0.0	0.070	109.5
BENZO(A)PYRENE	0.000	0.0	0.082	129.0
DIBENZ(A,H)ANTHRACENE	0.000	0.0	0.000	0.0
BENZO(G,H,I)PERYLENE	0.000	0.0	0.113	176.7
INDENO(1,2,3-CD)PYRENE	0.000	0.0	0.062	96.6
TOTALS	2.155	3380.2	1.023	1605.2

[1] Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-18. PARTICULATE COLLECTION SUMMARY[1]

SAMPLE PORTION	VOLUME SAMP (m^3)	BURN RATE (kg/h)	AVERAGE GASEOUS CONCEN. (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	EXTR ORG %	SAMPLE PORTION	VOLUME SAMP (m^3)	BURN RATE (kg/h)	AVERAGE GASEOUS CONCEN. (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	EXTR.ORG. %
		CHUNK DAY 1						CHUNK DAY 2			
ORG PART FILT 1	0.93	9.4	750.6	162816.3	4.5	ORG PART FILT 1	3.3	3.5	274.2	159741.1	6.8
ORG PART FILT 2	12.05	1.7	41.1	49295.8	11.9	ORG PART FILT 2	9.45	1	31.2	63616.8	34.5
TOTAL	12.98	2.3	91.9	81471.3	7.6	TOTAL	12.75	1.7	94.1	112864.6	13.6
MET PART FILT 1	5.19	4.9	269	111936.9		MET PART FILT 1	2.86	3.5	291.7	169936.1	
MET PART FILT 2	7.97	1.3	38.4	60228.9		MET PART FILT 2	9.08	1	35.3	71976.7	
TOTAL	13.16	2.7	129.3	97645.4		TOTAL	11.94	1.7	93.8	112504.8	
PM10 FILTER	0.53	14	819.6	119368.9		PM10 2	5.38	1.3	68.68	107721.9	
		SHRED DAY 1						SHRED DAY 2			
ORG PART FILTER	13.77	1.1	34	63023.6	22.6	ORG PART FILTER	12.43	1.3	53.5	83912.7	16.7
MET PART FILTER	13.29	1.1	35.7	66174.8		MET PART FILTER	15.56	1.3	40.1	62895.3	
PM10	5.4	0.85	74.5	178712.4		PM10	3.45	1.9	111.2	119335.2	

1 Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

The PM_{10} sampler was used to assess the amount of particulate found in the 10 μm or less range. Surface area is an important criterion when determining particulate emission standards and assessment. Particulate of this size, once airborne, tend to persist in the atmosphere for long periods and to become an inhalation problem. Owing to the nature of the sampler and the application to this study, several problems were encountered during data collection. The ambient sampler was designed to operate constantly at 4 cfm. This relatively high flow rate was difficult to maintain because of the rapid loading of the particulate filter. As the loading increased, the flow rate through the system decreased until the required flow rate could no longer be obtained. The 4 cfm flow rate was required to maintain the specific cut-off point for particulate sizing. As the flow rate decreased, the size of particulate reaching the filter increased; therefore, the data presented may not be valid because the required flow rate was not maintained.

3.6 AIRBORNE METALS

A separate particulate collection system was operated in order to verify and quantify the presence of metals collected from ambient emissions. Seventeen target metals reportedly found in tires were isolated.[9] The list was compiled from information on combusted tire-ash residues. Table 3-19 shows the results of the metal analyses. The results from the method blank are also included to demonstrate the marginal differences between the blank and collected samples. Many of the analyses are at or near instrument detection levels. The only significant differences between the blank and sample were found with lead and zinc. The lead results are extremely close to the instrument detection level of the element. The major difference was found in the zinc analyses. Tables 3-20 and 3-21 contain average gaseous concentration and emission rate estimates of the quantified metals for each burn condition. Many of the estimates are based on the detection levels themselves and are presented as "less than" quantities. The zinc data suggest that both average gaseous concentration and estimated emissions increased with increased burn rates.

TABLE 3-19. AIRBORNE PARTICULATE METALS ANALYSIS SUMMARY

METAL	BLANK	CHUNK DAY 1		CHUNK DAY 2		SHRED DAY 1	SHRED DAY 2
	FILTER TOTAL (mg)	FILTER 1 TOTAL (mg)	FILTER 2 TOTAL (mg)	FILTER 1 TOTAL (mg)	FILTER 2 TOTAL (mg)	FILTER TOTAL (mg)	FILTER TOTAL (mg)
ALUMINUM	0.02	0.03	0.01	0.02	0.02	0.02	0.02
ARSENIC	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
BARIUM	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CALCIUM	0.03	0.07	0.04	0.04	0.05	0.04	0.04
CHROMIUM	0.01	0.03	0.007	0.01	0.003	0.02	0.008
COPPER	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
IRON	0.06	0.16	0.04	0.07	0.02	0.1	0.03
MAGNESIUM	0.004	0.01	0.005	0.006	0.008	0.006	0.007
SODIUM	0.02	0.06	0.04	0.05	0.06	0.04	0.06
NICKEL	0.01	0.02	0.01	0.02	0.004	0.01	0.008
LEAD	<0.0005	0.002	0.002	0.002	0.003	0.0007	0.001
ANTIMONY	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
SELENIUM	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
SILICON	0.13	0.49	0.15	0.25	0.15	0.2	0.27
TITANIUM	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
VANADIUM	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
ZINC	0.01	0.44	0.14	0.36	0.09	0.14	0.29

TABLE 3-20. AIRBORNE PARTICULATE METALS QUANTITATION AND EMISSION SUMMARY: "CHUNK" CONDITION[1]

	CHUNK DAY 1				CHUNK DAY 2			
	1ST PART FILTER VOL SAMP = 5.19 m^3 BURN RATE = 4.9 kg/h		2ND PART FILTER VOL SAMP = 7.97 m^3 BURN RATE = 1.4 kg/h		1ST PART FILTER VOL SAMP = 2.86 m^3 BURN RATE = 3.5 kg/h		2ND PART FILTER VOL SAMP = 9.08 m^3 BURN RATE = 1.0 kg/h	
METAL	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m^3)	ESTIMATED EMISSIONS (mg/kg TIRE)
ALUMINUM	0.0058	2.4	0.0013	1.8	0.0070	4.1	0.0022	4.5
ARSENIC	<0.0001	0.0	0.0000	0.0	<0.0002	<0.1	<0.0001	<0.2
BARIUM	<0.0019	<0.8	<0.0013	<1.9	<0.0035	<2.0	<0.0011	<2.2
CALCIUM	0.0135	5.6	0.0050	7.3	0.0140	8.1	0.0055	11.2
CHROMIUM	0.0058	2.4	0.0009	1.3	0.0035	2.0	0.0003	0.7
COPPER	<0.0004	<0.2	<0.0003	<0.4	<0.0007	<0.4	<0.0002	<0.4
IRON	0.0308	12.8	0.0050	7.3	0.0245	14.3	0.0022	4.5
MAGNESIUM	0.0019	0.8	0.0006	0.9	0.0021	1.2	0.0009	1.8
SODIUM	0.0116	4.8	0.0050	7.3	0.0175	10.2	0.0066	13.5
NICKEL	0.0039	1.6	0.0013	1.8	0.0070	4.1	0.0004	0.9
LEAD	0.0004	0.2	0.0003	0.4	0.0007	0.4	0.0003	0.7
ANTIMONY	<0.0039	<1.6	<0.0025	<3.6	<0.0070	<4.1	<0.0022	<4.5
SELENIUM	<0.0001	0.0	<0.0001	<0.1	<0.0002	<0.1	<0.0001	<0.2
SILICON	0.0944	39.3	0.0188	27.4	0.0874	50.9	0.0165	33.7
TITANIUM	<0.0096	<4.0	<0.0063	<9.2	<0.0175	<10.2	<0.0055	<11.2
VANADIUM	<0.0096	<4.0	<0.0063	<9.2	<0.0175	<10.2	<0.0055	<11.2
ZINC	0.0848	35.3	0.0176	25.6	0.1259	73.3	0.0099	20.2
TOTALS	<0.2784	<115.8	<0.0725	<105.6	<0.3361	<195.8	<0.0596	<121.6

SAMPLE FILTERS CONTAINED IN ALUMINUM FOIL—POSSIBLE ALUMINUM CONTAMINATION
SAMPLE FILTERS MADE OF QUARTZ—POSSIBLE SILICON CONTAMINATION

[1] Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

TABLE 3-21. AIRBORNE PARTICULATE METALS QUANTITATION AND EMISSION SUMMARY: "SHRED" CONDITION[1]

	SHRED DAY 1 PART FILTER VOL SAMP = 13.29 m3 BURN RATE = 1.1 kg/h		SHRED DAY 2 PART FILTER VOL SAMP = 15.56 BURN RATE = 1.3 kg/h	
METAL	AVERAGE GASEOUS CONCENTRATION (mg/m3)	ESTIMATED EMISSIONS (mg/kg TIRE)	AVERAGE GASEOUS CONCENTRATION (mg/m3)	ESTIMATED EMISSIONS (mg/kg TIRE)
ALUMINUM	0.0015	2.8	0.0013	2.0
ARSENIC	<0.0001	<0.2	<0.0001	<0.2
BARIUM	<0.0008	<1.5	<0.0006	<0.9
CALCIUM	0.0030	5.6	0.0026	4.0
CHROMIUM	0.0015	2.8	0.0005	0.8
COPPER	<0.0002	<0.4	<0.0001	<0.2
IRON	0.0075	13.9	0.0019	3.0
MAGNESIUM	0.0005	0.8	0.0004	0.7
SODIUM	0.0030	5.6	0.0039	6.0
NICKEL	0.0008	1.4	0.0005	0.8
LEAD	0.0001	0.1	0.0001	0.1
ANTIMONY	<0.0015	<2.8	<0.0013	<2.0
SELENIUM	<0.0001	<0.2	<0.0001	<0.2
SILICON	0.0150	27.9	0.0174	27.2
TITANIUM	<0.0038	<7.0	<0.0032	<5.0
VANADIUM	<0.0038	<7.0	<0.0032	<5.0
ZINC	0.0105	19.5	0.0186	29.2
TOTALS	<0.0537	<99.5	<0.0558	<87.5

[1] Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is unknown how well this dilution represents ambient air exchange under actual conditions.

SECTION 4

SUMMARY AND CONCLUSIONS

The primary goal of this project was to characterize potentially harmful emissions from the simulated open burning of scrap tires. The simulation was necessarily crude, because it would be extremely difficult to match the burning of the equivalent of two tires with a 6 million tire, full-scale, stockpile fire. Nevertheless, the study allowed the investigators to identify and measure gaseous emissions and directly relate this information to a mass burn rate. This task was accomplished by accurately measuring dilution volumes, sample volumes, and weights of tire material combusted.

It is unknown how well the concentrations obtained from this study represent those at an actual tire fire. The dilution air added to the burn hut was used not only to control known volumes introduced, but to simulate ambient conditions as well. It is probable that the same types of compounds identified during this study are emitted during an actual fire, but whether the average gaseous concentrations and estimated emissions are comparable is uncertain. A comparison with limited data collected at the Winchester, Virginia fire by NIOSH,[11] indicates that reasonable agreement exists within several measurement areas. Many of the same compounds were identified in actual plume samples. Particularly good agreement exists in PAH plume measurements. NIOSH reported ambient concentrations of total PAHs are generally within the same order of magnitude as average gaseous concentrations obtained during testing. Measurements of CO also indicate similar agreement as well as do metals measurements. Both the lead and zinc measurements show similar values both in gaseous concentration and relative concentration between the two metals. It may be reasonable to assume that the estimates obtained during this study may be within an order of magnitude of emissions realized from actual stock pile fires.

The results of this study pose a variety of pertinent topics and questions regarding tire fires. How far does the particulate from a stockpile fire carry? Are evacuation procedures for populations in the

proximity of stockpile fires sufficient? Is it good policy to continue to let tire fires burn themselves out? A greater potential for harmful organic emissions seems to exist at lower burn rates; thus a smoldering tire fire may be more harmful than one that is burning out of control. The identification of significant quantities of benzo(a)pyrene in the particulate extracts warrants serious concern. High emissions of other noxious compounds, particularly benzene, with concentrations often exceeding 1 ppm, suggest that uncontrolled scrap tire combustion poses significant health risks.

The results from the airborne metals portion of the study were inconclusive. Maximum values were presented, often based on detection levels. Emissions of lead and zinc may reach significant quantities. Chemical analysis of ash residues reveals that zinc comprises nearly 50 percent of the total residue.[9] Evidently, the other metals known to be contained in tires remain in the ash residue. Although no attempt was made to analyze ash residue, significant quantities of metals present in the ash could potentially be leached out into groundwater systems, posing another major problem.

The values obtained by the on-line analyzers for normal combustion gases showed that as burn rate increased, the amount of CO, SO_2, and unburned hydrocarbons also increased. High burn rate conditions were not fully evaluated, so greater quantities of these gases, particularly SO_2, may be emitted during a stockpile fire. Tires contain a significant amount of sulfur, so high emissions of SO_2, while likely only a minor contributor to the acid rain problem, could have significant local consequences.

This study was designed to identify the potential chemical hazards from tire fires on a small-scale, simulation basis. The study reveals the potential for the emission of great amounts of organic compounds, primarily aromatics, some of which may be extremely harmful. Although the estimates of average gaseous concentrations and estimated emissions are crude, the trends presented in regard to burn rate may be helpful in directing further research and control efforts. The fact that the "SHRED" condition resulted in a lower burn rate indicates that the gaps between the tire material provide the major avenue of oxygen transport. Oxygen transport appears to be a major if not *the* controlling mechanism for sustaining the combustion process. This fact could have advantageous implications for those attempting to combat tire fires. It may be possible to fill the gaps between tires with a foam inhibitor, potentially suffocating the fire from within.

SECTION 5

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APPENDIX A

QUALITY CONTROL EVALUATION REPORT

The quality control measures taken during this study were performed to ensure that the data collected adequately represented the simulation of the open burning of scrap tires. The data quality objectives determined and procedures used during testing sampling and analysis are found in the Quality Assurance Project Plan (QAPP) (QTRAK No. 89007, AEERL Category III).

Table A presents the data quality summary for accuracy, precision and completeness achieved along with original goals for respective methods of measurement or analysis used during testing. As the table indicates, all project goals were obtained with the exception o. the SO_2 measurements. As stated earlier, the accuracy limits on Days 1 and 2 of the SHRED condition were exceeded during the day's end span check. Although the limits were exceeded, the data were presented along with data collected during valid operating conditions. Since the problems associated with the operation of the instrument were immediately noticeable, it was possible to isolate areas of likely valid data from obvious invalid data. In addition, although the SO_2 information is important, it is not critical. Determining the order of magnitude of SO_2 levels was adequate for this study, and this was obtained.

Prior to sampling, all dry gas meters were calibrated using an NBS traceable calibration system. Correction factors were determined for each meter. The dilution air volumes were determined using a pitot measurement system.

The quantitation of volatile organic compounds was determined using the response factor obtained during toluene calibration. The response of individual identified compounds in relation to toluene was not determined. The quantitation of chromatographable semi-volatile organic compounds was determined using the response factor of the TCO standard calibrations. Again, responses of individual identified compounds was not determined.

TABLE A. DATA QUALITY SUMMARY FOR ACCURACY, PRECISION, AND COMPLETENESS

Measurement	Accuracy (% Bias) Goal	No. Points	Achieved (Avg.)	Precision (% RSD) Goal	Achieved	Completeness (%) Planned	Achieved
O_2	±20	8	1.4	10	2.6	>90	100
CO	±20	8	2.0	10	0.7	>90	100
CO_2	±20	6	0	10	4.1	>90	100
THC	±20	8	12.0	10	1.5	>90	100
SO_2	±20	8 (6)*	-10.7 (-1.2)*	10	38.4 (3.9)*	>90	50
Volatile Organics GC/MS	±50	9	-3.1	25	7.9	>90	100
TCO GC/FID	±15	9	4.6	15	5.9	>90	100
GRAV	±20	2	-1.5	20	1.7**	>90	100

*With 2 failing points removed.
**Relative Percent Difference

$$\text{Accuracy (expressed as percent bias)} = \frac{\text{measured - true}}{\text{true}} \times 100$$

$$\text{Precision (expressed as percent relative standard deviation)} = \frac{\text{measured standard deviation}}{\text{measured average}} \times 100$$

Two performance evaluation audit samples were supplied by the Research Triangle Institute (RTI): sample one, PAH-A, was used to evaluate just the instrument performance of PAHs in the SoRI laboratories; the second sample, PAH-B, was used to evaluate the extraction efficiency of PAHs from XAD-2, and the instrument performance. The results of the audit sample PAH-A indicate that a systematic negative bias of approximately 60 percent existed. The results are being further analyzed because of discrepancies in the dilution factors. The results of audit sample PAH-B show extraction efficiencies ranging from 14-88 percent for four test analytes. No systematic bias was observed.

Because the major objective of the project is to qualitatively characterize the PAHs in the emissions, the wide range of quantitative recoveries are not expected to affect the validity of the data.

In summary, the QA project objectives set forth have been obtained and the data collected from this study is sufficient to meet project objectives.